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Washington, D.C. 20591

Frequency Management Engineering Principles—Spectrum Measurements

(Reference Order 6050.23)

Joseph D. Fretz

August 1982

Final Report

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16. Abstract

Federal Aviation Administration personnel are frequently involved in the resolution of interference complaints. The skillful use of measurement equipment can be essential to the successful resolution of such complaints. This report provides a summary of the spectrum measurement techniques applicable to Federal Aviation Administration facilities using the radio frequency spectrum. It is oriented toward electromagnetic compatibility measurements made by frequency management engineers but is of interest to anyone involved in radio frequency measurements.

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English/Metric Conversion Factors

Length

From \ To	Cm	m	Km	in	ft	s mi	nmi
Cm	1	0.01	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
S mi	160,900	1609	1.609	63360	5280	1	0.8688
nmi	185,200	1852	1.852	72930	6076	1.151	1

Area

From \ To	Cm^2	m^2	Km^2	in^2	ft^2	S mi^2	nmi^2
Cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
Km^2	1×10^{10}	1×10^{6}	1	1.55×10^{9}	1.08×10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
S mi^2	2.59×10^{10}	2.59×10^{6}	2.590	4.01×10^{9}	2.79×10^{7}	1	0.7548
nmi^2	3.43×10^{10}	3.43×10^{6}	3.432	5.31×10^{9}	3.70×10^{7}	1.325	1

Volume

From \ To	Cm^3	Liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal
Cm^3	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^2	1×10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0.0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl oz	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0625	0.0312	0.0078
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	946.3	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	2[illegible].0	0.1337	0.0050	128	8	4	1

Mass

From \ To	g	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

Temperature

$^{o}C = 9/5\ (^{o}F - 32)$

$^{o}F = 5/9\ (^{o}C) + 32$

PREFACE

Federal Aviation Administration personnel are frequently involved in the resolution of radio frequency interference complaints. The skillful use of measurement equipment can be essential to the successful resolution of such complaints. This report provides a summary of the procedures and equipment needed for electromagnetic spectrum measurements. It augments information contained in Order 6050.22A, Radio Frequency Interference Investigation and Reporting; and Order 6050.23, Frequency Management Principles, Spectrum Engineering Measurements.

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1. INTRODUCTION

1.1 Purpose

This report provides a summary of spectrum measurement techniques applicable to Federal Aviation Administration (FAA) facilities using the radio frequency spectrum. It is oriented toward electromagnetic compatibility measurements made by frequency management engineers but is of interest to anyone involved in radio frequency measurements.

1.2 Background

FAA facilities are subject to interference from numerous sources. These include other ground and airborne equipment; noise generated by many types of equipment;natural phenomena such as lightning or anomolous propagation; spurious responses in receivers; and improper equipment design, installation, or operation. Electromagnetic compatibility problems are increasing with the continuous growth in quantity and complexity of systems using the radio frequency spectrum.

Test equipment portability, complexity, performance, and reliability have improved considerably in recent years. There is now an abundance of equipment "tailor made" for specific applications. The use of the proper test equipment for an application improves both the accuracy and efficiency of measurements.

1.3 Use of the Spectrum in Air Traffic Control

The Federal Aviation Administration utilizes roughly 40,000 frequency assignments. Frequency assignments throughout the Federal Government exceed 150,000. Nongovernment frequency assignments exceed 200,000, with additional citizens band and unlicensed equipment such as garage door openers numbering in the millions. Brief summaries of FAA equipment characteristics and band allocations are given in Appendixes A and B.

1.4 Measurement Activities

As measurement equipment and procedures became standardized, the variety of measurement techniques employed eventually gave way to a limited number of techniques of proven effectiveness. It is desirable to use equipment that does not require modification; however, in some cases there may be a considerable cost savings if equipment is procured and various minor modifications made for FAA applications. Flight check aircraft usually provide adequate electrical power and suitable antennas for use with test equipment. Adding antennas or electrical power to an aircraft can be very expensive. Vehicles used for spectrum measurements are usually equipped with whatever equipment is required for a specific task. Order 6050.7, Radio Frequency Interference Measurement Vehicle, provides broad guidance in the use of specially equipped vans for spectrum measurements.

1.5 Regulatory Aspects

FAA frequency management activities involve various national, civil, and Government bodies (Federal Communications Commission (FCC), Interdepartment Radio Advisory Committee (IRAC), etc.), and United Nations (International Telecommunication Union (ITU), International Civil Aviation Organization (ICAO), etc.), on matters of frequency allocation, assignment, and interference. Technical support in the form of electromagnetic measurements is a valuable asset in preparing rulemaking positions, court cases, or other actions. The need for technical competence in the engineering aspects of the proceedings can be a deciding factor in the negotiations. Coordination for regulatory activities with other Government users of the spectrum normally is made through the Interdepartment Radio Advisory Committee. Coordination with nongovernment users normally is made through the Federal Communications Commission. Order 6050.18, Federal Communications Commission Liaison covers shared measurement responsibilities.

1.6 References

The following documentation may be useful to determine correct procedures, tolerances regulations, and remedies for an interference complaint:

(a) The Manual of Regulations and Procedures for Federal Radio Frequency Management, published by the National Telecommunications and Information Administration of the Department of Commerce.

(b) The FCC Rules and Regulations, Volumes 1 through 11, published by the Federal Communications Commission. Volume V, Part 87, "Aviation Services" is of particular interest for aviation activities, request the latest edition.

(c) The 6050 series of FAA orders. See Order 0000.3, Washington Headquarters Directives Checklist, and the regional directives checklists.

(d) The instruction manuals for FAA equipment normally contain data concerning receiver selectivity and transmitter emission spectrum (Section 6.2 and 6.3 of this report cover measurement procedures).

(e) The instruction manuals for measurement equipment along with any pertinent technical notes, journals, equipment newsletters, and other information supplied by the manufacturer.

(f) The current edition of the National Telecommunications and Information Administration's User's Manual, Frequency Management and Records System.

(g) Data base listings of the Government Master File maintained by the National Telecommunications and Information Administration. Also available from the Electromagnetic Compatibility Analysis Center of the Department of Defense. FAA listings are also available from FAA headquarters.

(h) Various United Nations' ICAO and CCIR publications related to the aeronautical bands and procedures for making measurements.

2. SPECTRUM SIGNATURES

2.1 Scope

This chapter presents general procedures used in obtaining spectrum signatures and contains a number of examples. The spectrum signature for a particular type of facility will be affected by factors such as multipath components at the monitoring point, equipment alignment, production line variations, and variations among manufacturers. The broadest emission spectrums can be expected among newer devices employing broad band power amplifiers or traveling wave tubes. The "cleanest" spectrums usually are found in single frequency crystal controlled transmitters with emission spectrums limited by a high quality factor filter at the output.

2.2 Receiver Selectivity

The counterpart of transmitter emission spectrums (spectrum signatures) in receivers is the receiver selectivity characteristic. Receiver selectivity normally would be measured with a simulated desired on-channel signal using a signal generator providing a fully modulated on-channel signal at the lowest usable level. Another unmodulated signal generator would be used to determine the interfering levels at various frequencies at which a 3 dB signal-to-noise ratio degradation would occur in the desired signal. These "maximum tolerable" interfering signal levels would then be plotted on a graph. This information is used to determine how much a frequency change or how much additional attenuation of an interference source would be needed to achieve satisfactory operation. The receiver selectivity curves supplied with equipment instruction manuals normally would be used, so that field measurement of selectivity is not required for FAA receivers (see procedure in Section 6.2).

2.3 Transmitter Emission Spectrum

A representative plot of transmitter emission spectrum (spectrum signature) normally would be included in the equipment instruction manual supplied with FAA equipment, so that spectrum signatures do not have to be obtained for FAA transmitters. A spectrum signature is useful in locating and identifying sources of interference (see procedure in Section 6.3).

2.4 Spectrum Analyzer

A number of high performance spectrum analyzers are available from several manufacturers of test equipment. They can be used to determine transmitter emission spectrums (spectrum signatures), measure frequency, harmonics, and frequency response. They normally achieve high sensitivity by feeding inputs directly into the first mixer at the lowest input attenuator setting. The mixer and input attenuator are also sensitive to overload and burn out. Usually ouputs are provided for use with strip chart recorders (for collection of large amounts of data) and with X-Y plotters (for plotting on graph paper). Records of spectrum analyzer outputs normally are obtained with an oscilloscope camera, avoiding problems with set-up time and non-linearities found in strip chart recorders and X-Y plotters. Temperature, line voltage, and random spectrum analyzer instabilities create drift problems when these devices are used as fixed tuned receivers operating with very narrow IF bandwidth.

2.5 Strip Chart and X-Y Plotters.

Strip chart recorders have the advantage of being able to quickly record a large number of spectrum analyzer scans without manual intervention. The trace is usually cleaner and easier to reproduce than prints from a camera. X-Y plotters can produce a very clean plot on conventional graph paper. These devices may be difficult to setup and frequently are plagued by circuit non-linearities, although they do provide a means of obtaining a spectrum signature from a field intensity meter. Photographic records are satisfactory for most applictions and, therefore, are preferred to either strip chart or X-Y plotter records. A record should be kept of pertinent equipment settings such as center frequency, decibels per division, IF bandwidth, and calibration of the X and Y axes.

2.6 Spectrum Signatures

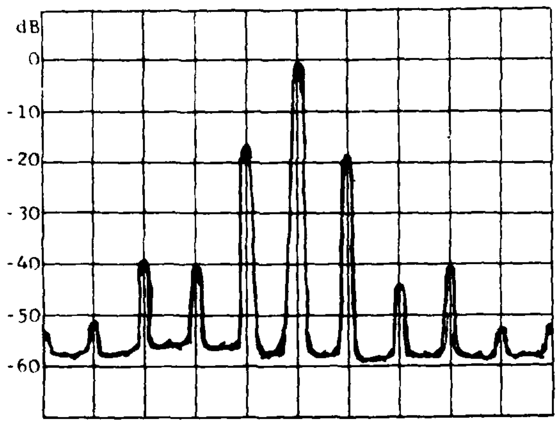
One means of identifying the sources of interference is a spectrum signature. It is possible to use spectrum signatures to discriminate between transmitter output devices such as broadband solid state amplifiers, magnetrons, klystrons, and traveling wave tubes. Multipath components from power lines, ground reflections, etc. will produce some distortion of a measured spectrum signature, but the effect is usually minor. Another factor affecting the measured emission spectrum is the IF bandwidth of the spectrum analyzer. For uniformity, a 1 kHz measurement bandwidth should be used when feasible. The shape of the IF bandpass of the spectrum analyzer should also be determined by measuring a zero bandwidth signal (unmodulated signal generator). This enables one to discriminate between spectrum analyzer response and the actual emission spectrum being measured.

Additional errors are created by intermodulation products generated within the spectrum analyzer. In general, if a decrease in input attenuation results in the level of a component of the display increasing more than the change in attenuation, or if an increase in attenuation results in the level of the component decreasing more than the change in attenuation; then that component is being generated partially or totally within the spectrum analyzer. The problem of spurious products is minimized by using sufficient input attenuation to avoid overload of the spectrum analyzer circuitry.

In the case of transmitters that are modulated with voice or other noise like signals that exhibit a modulation spectrum that falls off rapidly with increasing frequency, the occupied bandwidth (bandwidth within which 99% of the emitted power falls) can be measured with a spectrum analyzer. Provided that the IF bandwidth of the spectrum analyzer is small compared to the signal being measured, the approximate occupied bandwidth of the signal being measured is equal to the frequency span between the points on the display that are 20 decibels below the carrier frequency.

2.7 Vacuum Tube VOR

Figure 2-1, Vacuum Tube VOR Spectrum Signature

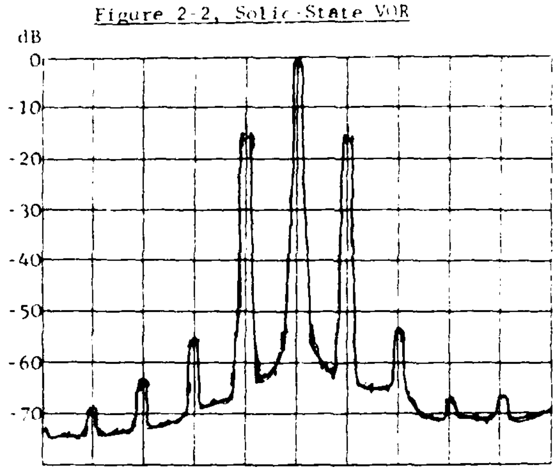


10 kHz/division, 117.1 MHz Center Frequency
IF bandwidth is 1 kHz

The older vacuum tube type VOR facilities do not have the low sideband levels necessary for the use of 50 kHz VOR channeling. Compare this spectrum signature with that for a solid-state VOR, figure 2-2.

2.8 Solid-State VOR

Figure 2-2, Solid-State VOR

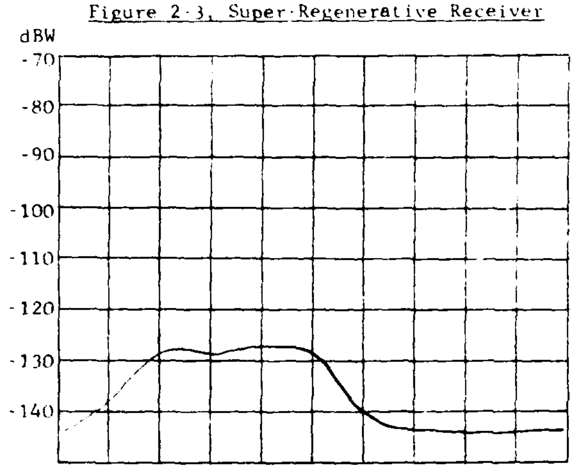


10 kHz/division, 117.1 MHz Center Frequency
IF bandwidth is 1 KHz

The solid-state VOR has lower sideband levels necessary for implementation of 50 kHz channeling.

2.9 Super-Regenerative Receivers

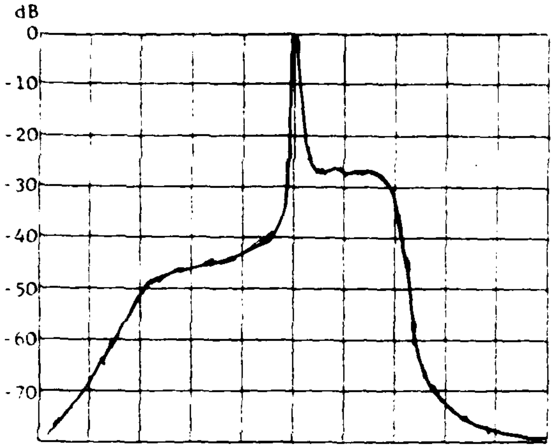
Figure 2-3, Super-Regenerative Receiver



10 MHz/division, 375 MHz Center Frequency
1 kHz effective IF bandwidth

This spectrum signature is for a modern super-regenerative garage door opener receiver equipped with an RF amplifier for isolation. Note that the energy is skewed toward frequencies below the operating frequency of 375 MHz. The measurements were made with a dipole 1 meter from the receiver. Since the emission is random noise, maximum analyzer sensitivity was obtained by utilizing a 300 kHz IF bandwidth and 100 Hz video filter; the plot is corrected to show levels (25 dB lower) that would be obtained with an IF bandwidth of 1 kHz. One microvolt into a 50 ohm load is -137 dBW or -107 dBm; the radiation level is very low.

Figure 2-4, GDO Transmitter

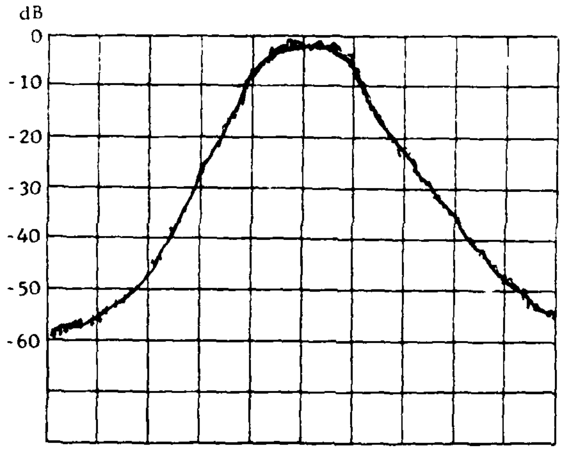


1 MHz/division, 375 MHz Center Frequency
1 kHz IF bandwidth

Although the 375 MHz carrier is obviously the strongest component of the garage door opener (GDO) transmitter spectrum, there is also substantial off channel emission that might cause problems.

2.10 TACAN/DME

Figure 2-5, TACAN/DME

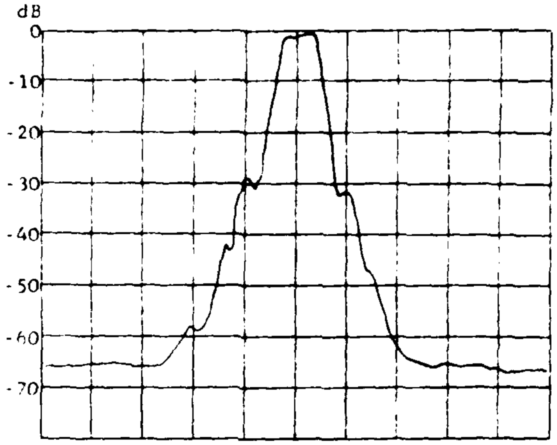


.2 MHz/division, 1205 MHz Center Frequency
300 kHz IF bandwidth

The spectrum signature is for the solid-state TACAN/DME. It is the envelope of a display taken with the video filter off and a 300 kHz IF bandwidth.

2.11 JTIDS

Figure 2-5, JTIDS

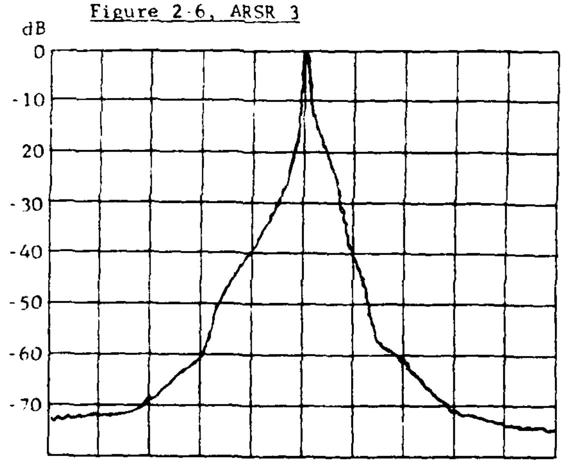


5 MHz/division, 1053 MHz Center Frequency
300 kHz IF bandwidth

The spectrum signature is for a single JTIDS channel. In actual operation, all 51 JTIDS channels (spaced every third TACAN channel) would be occupied. The composite, made up of 51 of the above emissions, would appear to cover the 960 MHz to 1215 Mhz band with voids at 1030 MHz ± 7 MHz and 1090 ± 7 MHz.

2.12 ARSR

Figure 2-6, ARSR 3

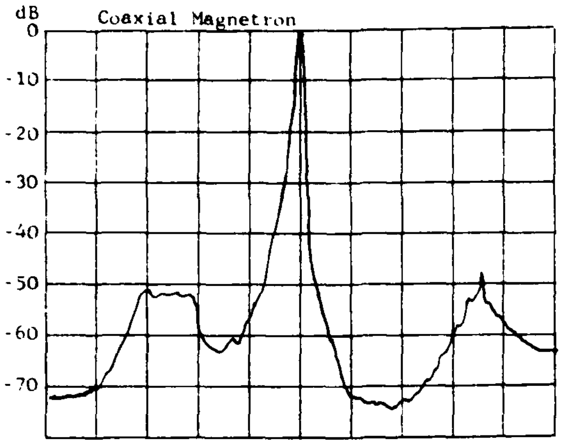


5 MHz/division, 1268.7 MHz Center Frequency
300 kHz IF bandwidth

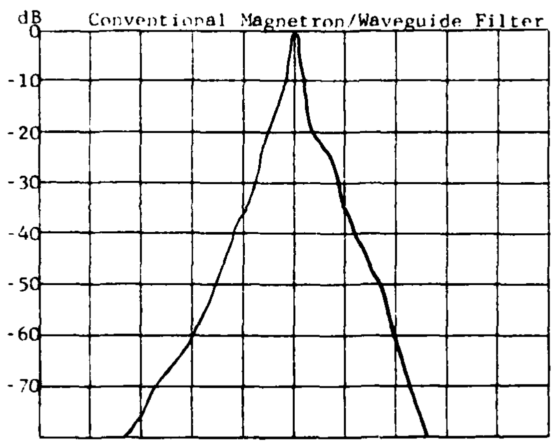
The above spectrum signature shows the sharp drop in spurious emissions at off channel frequencies that is characteristic of klystrons.

2.13 ASR

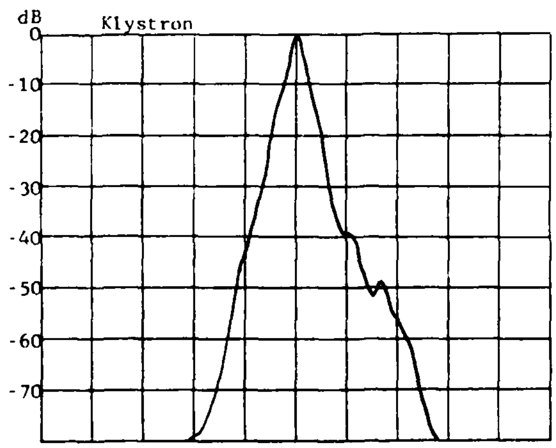
Figure 2-7, ASR



20 MHz/division, 2788 MHz Center Frequency
300 kHz IF bandwidth



20 MHz/division, 2890 MHz Center Frequency
300 kHz IF bandwidth



20 MHz/division, 2840 MHz Center Frequency
300 kHz IF bandwidth

The newer surveillance radars employ klystrons to minimize problems with off channel emissions. Although expensive, waveguide filters can be added to existing magnetron transmitters to reduce off channel emissions.

3. ROTATING ANTENNA PATTERNS

3.1 Scope

When an antenna is rotating, signal strength measurements associated with that antenna will exhibit a varying amplitude. The variation will be a function of the antenna's gain and rate of rotation. A plot of the antenna's pattern (gain as a function of azimuth, and gain as a function of elevation) can therefore be used to determine signal strength variations with time. Although reflections off of various terrain features will make each antenna pattern measurement unique, with proper precautions a good, representative plot of an antenna's pattern can still be obtained.

3.2 Use of Spectrum Analyzer

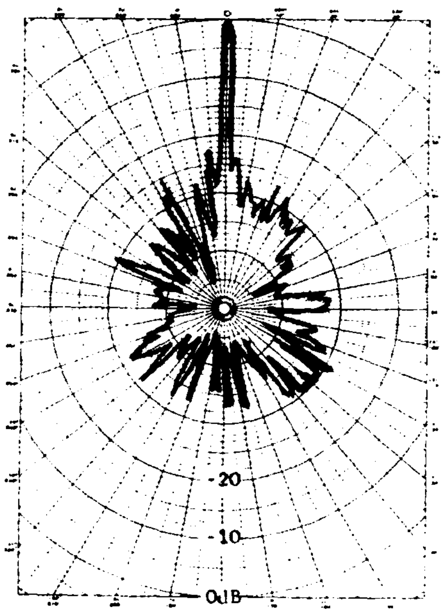
Numerous antennas are available for use with standard 52 ohm transmission lines or waveguide. These can be used in conjunction with a spectrum analyzer for antenna pattern measurements. The directivity of the antenna will affect the measured pattern. This is particularly true if there are strong sources of reflection to the side of the direct path that can be eliminated by use of a directional antenna. An antenna pattern can be obtained by tuning the spectrum analyzer to the frequency of the desired facility, using a slow enough sweep rate to display an entire period of rotation, and photographing the display. Monitoring sites should be several thousand feet from the antenna to minimize the gain loss due to negative elevation angles relative to the antenna main lobe.

3.3 Use of Strip Chart Recorder or X-Y Plotter

A strip chart recorder or X-Y plotter will give a plot that is much easier to read than a photographic record of a spectrum analyzer. They can be driven by the output of a field intensity meter, a monitor receiver AGC, or the output of a spectrum analyzer. Care must be taken in properly calibrating the non-linear Y-Axis response when using sources other than a spectrum analyzer. Attempts to use strip chart recorders or X-Y plotters with receivers not designed for such use should not be made because of the poor plot produced by non-linear receiver response.

3.4 ATCRBS

Figure 3-1, ATCRBS Antenna Pattern

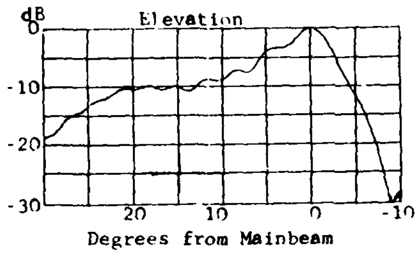


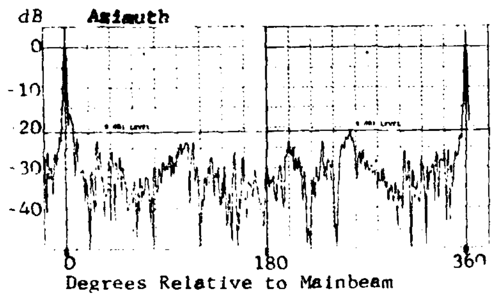
The above plot was manually transcribed from a strip chart recording onto five cycle polar graph paper. When a computer controlled measurement system is used, it is possible to have a polar plot produced during the measurements with scale factors set automatically. It would also be possible to reduce recorded data at a later time.

The pattern was taken at a 3/4 mile range to achieve a zero degree elevation angle relative to the ATCRBS antenna. The monitor antenna was fixed in position and the signal level recorded on a strip chart recorder. Note that the more directional the monitor antenna, the better the rejection of reflections that would distort the measured pattern. The polar plot was made by manually plotting points taken from the strip chart recording. The omnidirectional side lobe supression antenna obviously has to be shut off for such a measurement. For most applications a photographic, logarithimic plot obtained from a spectrum analyzer would be used, as it is both fast and accurate.

3.5 ASR

Figure 3-2. ASR Antenna Patterns





Frequency: 2791 MHz Period: 6.03 Seconds
Peak Power: 28.1 dBm into receiver

The above patterns are for the Burbank,California ASR-6.

3.6 Site Coverage

There are a number of methods for determining site coverage. Flight check aircraft may be used to verify that an air route is adequately covered. Another method is to use computer plots of coverage such as the Terrain Analysis Model or Site Analysis Model available form the Department of Defense's Electromagnetic Compatibility Analysis Center. Point to point propagation loss can be computed with programs such as the Master Propagation System (MPS), the Automated Digital System Engineering Model (ADSEM), the Path Loss Line-of-Sight Model (PLLM), the Free Space Path Loss/Power Density Calculations (for programmable calculators), Radio Propagation Over Irregular Terrain (RAPIT), SHADO, HORIZON, PROFILE, and the Point-wise Propagation Model (POPROP). As a general rule, the error in median propagation loss predictions can be expected to be up to 20dB when the path is long enough so that it grazes the surface of the earth (more than about 20 miles). Signal strength variation with time can be expected to have a 30 to 50 dB range. See Chapter 5 of Order 6050.17B, VHF/UHF/SHF Communications Links, for a brief discussion of these models.

4. INSTRUMENTATION

4.1 Scope

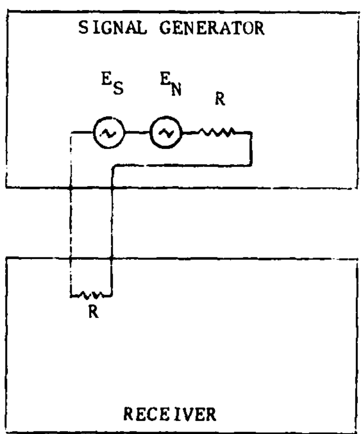
Use of the correct equipment for measurements enables a task to be completed quickly, accurately, and with a minimum of effort. This chapter discusses the equipment used for various measurements.

4.2 Noise Figure

Standards have been established for noise figure for certain categories of equipment. A noise figure measurement is not the same as a determination of sensitivity (covered in section 4.3, Spurious Products). Noise figure is defined as the ratio of actual noise developed in a receiver to the noise that would be developed in a hypothetical resistor equal to the input resistance (not reactance) of the receiver, expressed in dB. The hypothetical resistor would be at a temperature of 290° Kelvin which is 17° Celsius or 62° Fahrenheit. Noise figure also can be expressed as a noise temperature, the temperature in degrees Kelvin that the hypothetical resistor would need to produce the measured level of noise output.

Actual noise figure measurements can be expected to be several decibels higher than the value calculated from a measurement of receiver sensitivity (see section 4.3, Spurious Products). This is due to detector non-linearities and attenuation at the edges of the receiver IF passband, resulting in a decrease in the calculated value. Calculated values of noise figure normally are used for frequency management purposes. Noise figure may be calculated as shown in figure 4-1.

Figure 4-1, Noise Figure Calculation



E_S = Open Circuit Signal Generator RMS Modulation Envelope (AM), RMS Carrier Voltage (FM or Pulse)

E_N = Apparent Open Circuit Noise (Produced by Receiver) RMS Voltage

$E_N = X \sqrt{4\ KTBR}$

K = Boltzmann's Constant, 1.38×10^{-23}

T = Temperature, 290° Kelvin

B = Receiver Bandwidth

R = Signal Generator Output Impedance, Same as Receiver Input Impedance

$X = \dfrac{\text{Apparent Open Circuit Noise}}{\text{Open Circuit Noise at } 290^\circ \text{ K}}$

Noise Figure = 20LogX

Example:

E_S is determined by measurement to be 5 uVolts for a 12 dB signal-to-noise ratio in a receiver with a 36 kHz bandwidth, and 52 ohm input impedance. Then

$$E_N = X\sqrt{(4)\ (1.38 \times 10^{-23})(290)\ (3.6 \times 10^{4})(52)}$$

$$E_N = X\sqrt{3 \times 10^{-14}} \quad = \quad X(1.73)\ (10^{-7})$$

The measured noise level was 12 dB below 5 uVolts, or 1.25 uV.

$$E_N = 1.25 \times 10^{-6}$$

$$1.25 \times 10^{-6} = X\ (1.73)\ (10^{-7})$$

$$7.25 = X$$

$$20 \text{ Log } 7.25 = 17.5 \text{ dB noise figure}$$

Noise figure meters are available that operate directly from a receiver's IF output at the IF frequencies normally used for microwave link and radar systems. The noise figure of an IF amplifier also can be measured. Since the IF passband and detector characteristics normally do not vary significantly among FAA receivers of a given type, the use of a noise figure meter is no more precise than the measurement that would be obtained from a simple sensitivity measurement. In addition, errors are created by the lack of a either continuous wave or modulated carrier receiver input when a noise figure meter is used. The lack of such a carrier alters detector performance so that the measurement does not reflect performance under actual operating conditions. For these reasons the computation of noise figure from a measurement of receiver sensitivity is preferred to the use of a calibrated noise source and noise figure meter.

4.3 Spurious Receiver Products

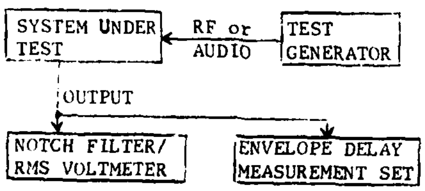
There are two points at which the impact of interference normally would be evaluated. One is the RF input to a receiver where the ratio of interference to receiver noise would be determined. The other point is the output of a system where the demodulated signal is delivered to the user. This section is concerned with the measurement of spurious products at the output of a system.

The technique consists of using a test signal, typically 400 Hz, used to fully modulate a transmitter (or signal generator) or other system input such as a telephone line or cable. At the output the level of the 400 Hz test signal is measured. an averaging type voltmeter also could be used for this measurement. The 400 Hz test signal is then removed with a notch filter and a reading made of any spurious products present. Signal to noise ratio (SNR) can be determined as follows:

$$\text{SNR} = 20 \text{ Log } \frac{\text{RMS test signal voltage}}{\text{RMS spurious products voltage}}$$

Sensitivity is specified either in terms of tangential sensitivity (a point at which the desired signal is equal to the noise)or in terms of a signal to noise ratio at which a squelch circuit would activate (i.e. shut off the receiver). In either case both the test signal voltage and the spurious products voltage would have to be measured. It is important to record the level of modulation at which the transmitter is considered to be fully modulated since many AM transmitters are not capable of reaching 100% modulation. The receiver sensitivity is specified in terms of an RMS carrier level, with a specified modulation (if AM or FM), providing a specified signal to noise ratio.

Figure 4-2, Spurious Products Measurement

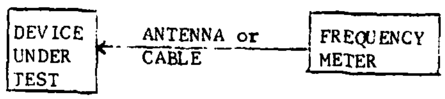


The bit error rate for various signal to noise ratios is contained in the instruction manuals for digital equipment. In addition to an acceptable SNR, an acceptable level of envelope delay at various frequencies must be maintained. It is necessary to discriminate between malfunctions due to interference reducing the signal to noise ratio and malfunctions due to changes in the envelope delay characteristics of a system. In the case of receivers used for pulsed RF, the sensitivity (automatic gain control bus, not RF/IF gain controls) would be set at maximum and the detector output monitored at a point prior to any threshold detection circuitry.

4.4 Frequency

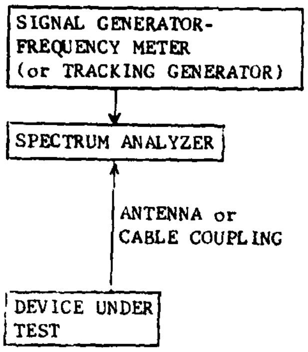
The ability of a frequency meter to provide accurate readings in the presence of modulation varies with the design and the adjustment of the meter. Carrier frequency often shifts when modulation is applied. Drift will result from line voltage and temperature changes. Another source of error is defective logic or counting circuitry in the frequency meter or frequency synthesizer of equipment being examined; it is possible for such errors to be small enough to provide a reasonable but incorrect frequency reading. A calibrated, combined signal generator/frequency meter (or a tracking generator used with a spectrum analyzer) can be used to verify correct frequency meter operation. There are several test configurations that can be used depending upon the available equipment (figures 4-3 through 4-5) and required sensitivity.

Figure 4-3, Use of Frequency Meter



Frequency is read directly from the frequency meter. Sensitivity is limited to levels on the order of one tenth of a volt.

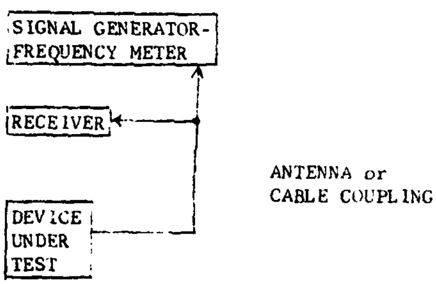
Figure 4-4. Use of Frequency Meter-Signal Generator, Spectrum Analyzer



Match signal generator and device frequencies by visual observation of spectrum analyzer, read frequency from the frequency meter.

Note: Damage to the spectrum analyzer should be avoided. Do not exceed the maximum input level to the mixer, typically on the order of one volt.

Figure 4-5. Use of Frequency Meter-Signal Generator, Receiver



Obtain an aural zero beat between the device frequency and the signal generator frequency, read the frequency from the frequency meter.

4.5 Power

The need may arise to determine whether or not a transmitter is operating at the correct power level. This would occur if maintenance logs at a facility are absent or the functioning of the power meter used is questionable. Monitor ports are provided on most waveguide runs. Suitable couplers would have to be added to most transmission lines. In any case, the transmitter would be connected to either an antenna or dummy load and sufficient attenuation provided to protect the power meter or spectrum analyzer used. When measuring to determine compliance with power output limitations it is important to consider waveguide/transmission line losses and determine the power delivered to the antenna and not the power delivered to the transmission line. Waveguide/transmission line losses can be obtained from commercial electronics handbooks, the equipment instruction manuals, and related FAA handbooks.

4.6 Field Strength, Far Field

(a) General: Electromagnetic compatibility problems can be created by electrostatic, magnetic, and electromagnetic fields. These may be propagated through space; through conductors, or through substances with high permeability or permittivity. Problems concerning magnetic and electrostatic fields usually are precluded by proper equipment design, and are not covered as part of this section. The improper specification of appropriate maximum levels for electromagnetic radiation from equipment and for susceptibility to external fields occasionally creates problems concerning electromagnetic radiation. This section is concerned with the measurement of electromagnetic field strengths produced by equipment and the measurement of susceptibility to such fields (see Appendix E for electromagnetic radiation hazard criteria).

There are numerous government and industrial specifications and standards concerning electromagnetic radiation. Problems in the field usually are not the result of failure to meet these standards, but are usually the result of the need for greater isolation than that considered necessary when a facility was installed. A good example is the frequency engineering of military radars that can operate at fixed azimuths. Although the interference produced by these radars at an FAA airport surveillance radar site may be entirely satisfactory when the military systems are rotating, interference may become unacceptable when the main lobe is directed at the FAA facility on a continuous (non-rotating) basis. In this case separation criteria did not account for the possibility of fixed azimuth operation of the military system.

Field strength measurement equipment may include portable equipment of the type used in aircraft, special purpose receivers such a ELT locators, field intensity meters, spectrum analyzers, calibrated wideband omnidirectional field strength meters used for electromagnetic radiation hazard measurements, and the necessary adjuncts such as cables, antennas, and pre-selector filters. The need for features such as portable operation outside of a van, direction finding, high sensitivity, long term measurements, the rejection of unwanted signal inputs, the need to locate sources of reflection, and accuracy dictates the type equipment to be used.

(b) Site Survey:

Figure 4-6, Field Strength Measurement

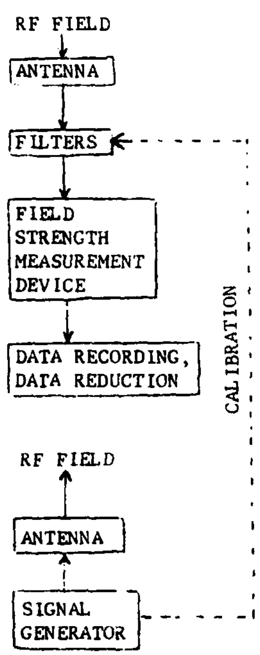


Figure 4-6, above, depicts the general equipment layout used to determine the strength of an RF field at a site, calibrate the device used to measure field strength, and the use of a signal generator to create a field of known strength. All of the elements shown will not be needed in every case. For instance, a factory calibrated meter for electromagnetic radiation hazard measurements would be used with only a probe type antenna attached through a cable.

Some of the commonest errors made with devices used for field strength measurement are 1) failure to calibrate the receiver 2) failure to account for the "duty cycle" of pulsed systems 3) the use of an incorrect measurement bandwidth 4) destroying the measurement device by placing the antenna close to a source of high power RF and 5) obtaining incorrect readings (too low) by the use of an antenna in its near field region.

The demarcation point between the near field and far field regions of an antenna is given by

$$\text{Distance} = \frac{2\ (\text{Antenna Diameter})^2}{(\text{Wavelength})}$$

where lengths are all measured in the same units and the wavelength is the wavelength for the frequency of operation. The wavefront does not expand in an "inverse square law" fashion at closer distances to the antenna, resulting in an antenna gain indication that is lower than that determined by far field measurements.

Example: For a frequency of 8 GHz, wavelength of .125 ft., an 8 ft. parabolic antenna then

$$\text{Distance} = \frac{2\ (8\ \text{ft.})^2}{(.125\ \text{ft})} = 1030\ \text{feet}$$

The above approximation does not cover side lobes, losses that reduce the effective diameter of an antenna, or elliptical antenna shapes. Appendix C provides a free space loss nomograph that can be used to obtain a more accurate approximate demarcation point using the following formula:

$$\text{Distance} = 5X$$

where X is the distance at which the free space loss is equal to twice the antenna gain in the direction of interest. A measurement of antenna gain at this point normally would be within 1 dB of the true far field gain.

Example: The main lobe of an antenna has a gain of 43.4 dB at 8 GHz. The required distance for a free space loss of 86.8 dB at 8 GHz is found to be 190 feet from the nomograph in Appendix C.

$$\text{Distance} = 5\ (190) = 950\ \text{feet}$$

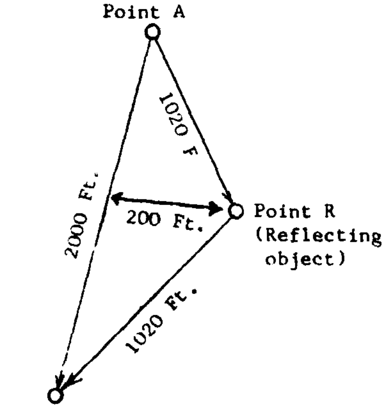
A measurement of the main lobe gain made 950 feet from the antenna could be expected to be within 1 dB of the "infinite" distance value (neglecting the impact of reflections off the ground or other terrain features).

Site surveys at ground level (as opposed to airborne) are used in a variety of cases. It is desirable to investigate the field strength and pulse rates of other radar systems at a prospective site for a new FAA facility when data base listings show a number of sites in the area (75 mile radius). Surveys may be required at existing facilities to determine sources of interference as well as equipment susceptibility to electromagnetic fields. It is important to maintain complete and accurate records of measurement equipment settings, the equipment configuration used, weather conditions when they might impact measured signal levels, and other pertinent data. This is particularly important when legal action may have to be taken to eliminate harmful interference (see Order 6050.22A, Radio Frequency Investigation and Reporting for the general procedures for resolving interference complaints).

4.7 Multipath Measurements

It is necessary to determine the antenna pattern of directional antennas to compute coupling through side lobes. The greatest source of error in such measurements is multipath caused by signal components reflected off various terrain features. The time delay between the primary wavefront and various reflected components as well as the intensity of the various components can be measured using specialized equipment.

Figure 4-7, Multipath Example



Note that although the indirect propagation path shown in figure 4-7 is 200 feet from the primary path, the path length differences are only 40 feet. This corresponds to a time delay of less than 40 nanoseconds, resulting in a requirement for wide bandwidth in multipath measurement equipment. Since frequency is a relatively minor factor compared to the size, orientation, and electrical impedance of reflecting objects; any practical test frequency will provide a good indication of the intensity and delay that would occur at the frequency of interest. Multipath measurement equipment has been constructed using a continuous wave transmitter at one end of a path and a receiver at the other end. The use of a pseudo-random 512 bit noise pattern modulating the transmitter permits a digital integration to be performed in the associated receiver, increasing the effective transmitter power by 27 dB (512 times). A transmitter power of ten watts operating in the 8.4 to 8.6 GHz band is typical. If it found that a potential source of multipath does not produce sufficiently strong reflections to affect an antenna pattern measurement, then no special precautions are necessary. If strong reflections exist, a different receiver location, the use of very directional antennas, or the use of wire screen shields may be necessary. The multipath measurement systems also can be used for such purposes as the evaluation of the reflectivity of terrain features at navigational aid sites, and the evaluation of atmospheric multipath along point-to-point communications links. These systems are experimental rather than operational devices at present.

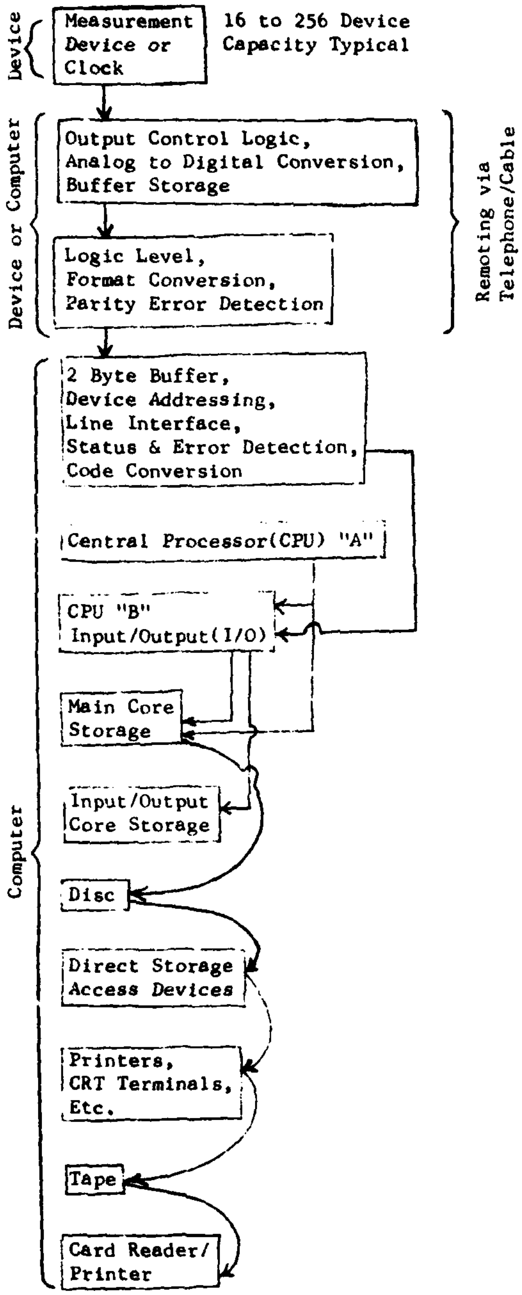
4.8 Automatic Monitoring

Occasionally a requirement developes for a long term measurement of a parameter such as frequency or field strength. For instance, there may be need to determine the percentage of time during a day an interfering signal exceeds a certain level, and the times and duration of these interfering signals during the day. Collecting and reducing this data manually would be very laborious. An automated data collection and reduction system makes such long term measurements practical.

Figure 4-8 is a block diagram of a hypothetical automated data collection system. The figure shows various devices that might be used and does not represent an actual system. Data and the time/date may be recorded on an instrumentation recorder for later playback into an automated system for data reduction; this may require the use of a large number of tapes when considerable data is involved. The advantage of real time data reduction is that the raw data can be collected over a sampling interval (e.g. one hour) the data reduced to obtain the desired statistics, then the storage device (e.g. floppy disc) holding the old raw data (dumped) can be reused to record raw data for the next sampling interval.

One of the biggest problems encountered when assembling a system is the need to adapt a measuring device to an incompatible input/output port of a computer. These problems include filtering and shielding from sources of interference such as nearby transmitters, the need for buffer storage to prevent loss of data, error detection, differing data transfer rate capabilities, format incompatibilities, and the need to provide measurements at a precise rate (such as one per second). The equipment used to interface a measurement device to a computer may be incorporated into the measurement device,

Figure 4-8. Automated Data Collection



fabricated as a separate unit, or incorporated into the computer.

Cost, reliability, and portability limit the size and features that would be used on a computer. A practical system for field use might consist of an 8 bit microprocessor (hard wired programmed) CPU (central processing unit) with an input/output terminal, printer, two floppy discs, a 16,000 word core storage, a clock, and capability for 16 analog or digital inputs. Figure 4-8 shows two CPU's; the use of a dedicated CPU "B" for handling input/output (I/O) operations results in much faster processing times than if CPU "A" handled both I/O and data reduction programs. Since the data reduction programs would only be run periodically (e.g. once an hour), a practical system can function satisfactorily with one CPU. The I/O core storage would be a relatively small memory, and used only if two CPU's were used. Card readers/printers and paper tape readers/printers are becoming dated with the increasing use of cathode ray tube (CRT) displays. Programs may be written onto replaceable read-only memory (ROM) in small systems. Direct storage access devices are becoming increasingly popular; for instance a clock might write the time/date directly into specified areas of core storage, avoiding the use of the CPU to input this data. The exact system used for measurements depends upon factors such as cost, equipment availability, ease of programming, portability, reliability, accuracy required, and the time available to program and set up the equipment.

4.9 Miscellaneous

Many items will be needed other than the basic test equipment (frequency meters, etc.) in order to make measurements. These can include items such as portable electrical generators, various cables and connectors, calculators, surveying equipment, drafting supplies, mobile/portable communications equipment, air conditioning for sensitive equipment, equipment supplies (plotter paper, camera film, etc.), and others. An order for a special cable assembly or waveguide components may take months to fill. It is important to have an adequate stock of such miscellaneous equipment if a quick response capability is to be maintained.

5. COMPUTATION OF PERFORMANCE

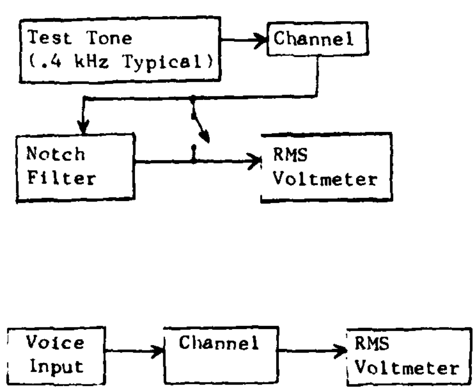
5.1 Scope

This chapter presents methods for computing performance of a facility based upon relatively easily measured data, as opposed to the use of difficult and expensive direct performance measurements. The procedures were developed from data collected through direct performance measurements, and hence are more accurate than purely theoretical analyses. Performance computations provide a good rough estimate of whether or not an interference problem exists, and indicate whether or not more elaborate measurements are necessary.

5.2 Voice Intelligibility

Work done at the FAA Technical Center in 1969 related intelligibility scores to air traffic control message intelligibility, report number NA-69-21 and RD-68-59, Effects of Selective System Parameters on Communications Intelligibility. Measurements made at the Institute for Telecommunication Sciences in 1980 related various types and levels of interference to intelligibility scores, report number FAA-RD-80-71, Voice Performance Measurements. This work has been used as the basis for the following technique for determining an intelligibility score and whether or not the level of interference is acceptable.

Figure 5-1 Spurious Products Measurement



Voice input is used only when it is not possible to use a test tone, since measurement of quantization noise (distortion) requires that a test tone be used. In some cases the volt meter used to measure noise will include an FlA or "C message" weighting filter (telephone company type noise meter), this factor is included in the intelligibility computation table. When a test tone is used, the RMS signal level (the test tone) is measured with the notch filter bypassed. The RMS noise level is then measured by using the notch filter to remove the test tone. The signal to noise ratio(SNR) is the level (in dB) of the test tone minus the level (in dB) of the noise. When voice serves as the test signal the RMS voice level is taken to be 13 dB below the maximum reading of the RMS voltmeter, the noise is the reading obtained during pauses in the speech, this gives a rough measure of signal to noise ratio in dB using the dB scale of the RMS voltmeter. An intelligibility score can be obtained as show in figure 5-2.

Figure 5-2, Voice Intelligibility

Score, Percent Intelligibility =

$$100\left[1 - e^{-.5\,(10^{\frac{Y}{20}})}\right]$$

Where Y is the measured signal to noise (SNR) plus an adjustment for the type interference as shown the table below:

Adjustment (Add to SNR) (in decibels)	Minimum Acceptable Measured SNR	Type Interference (Noise) (200-4kHz)
12	4	Sine Wave (e.g. a heterodyne)
6	10	Voice (cross talk)
0	16	Quantization noise (Distortion)
-4	20	Random Noise (no filter on meter)
-10	26	Random Noise (FIA or C message filter)

These values should not be confused with those used for maintenance or equipment specification. Maintenance and specification criteria are normally based upon random noise only (worst case). Maintenance values must be considerably higher than those given in figure 5-2 to allow for normal circuit variability. Likewise, specification values must be substantially higher than maintenance values to allow for production and installation tolerances.

Example:

A circuit exhibits heavy random noise as a result of interference desensitizing a receiver. The signal to noise ratio is measured using an RMS voltmeter (with no F1A or C message filter) and the signal to noise ratio is found to be 18 dB. Since the minimum acceptable measured SNR (see the second column of figure 5-2) is 20 dB, the circuit is not acceptable for air traffic control use. The intelligibility score is

$$\text{Score} = 100 \left[1 - e^{-.5\,(10^{\frac{18-4}{20}})}\right] =$$

$$100 \left[1 - e^{-.5\,(10^{.7})}\right] =$$

$$100 \left[1 - .082\right] = 91.8 \text{ percent}$$

The intelligibility score is that which would be obtained with a 50 phonetically balanced word group. A 95% score corresponds to essentially a 100% air traffic control message intelligibility. The corresponding (95% score) measured signal to noise ratios are shown in the second column (minimum acceptable measured S/N) of the table in figure 5-2.

Impulse noise and intermittent interference require special treatment. RMS voltmeters may not accurately measure impulse noise; the output should be monitored with an oscilloscope for clipping due to meter overload. Components above 4 kHz and below 200 Hz must be removed by use of filtering. Repetitive impulses with a sine wave quality would correspond to the sine wave criteria of figure 5-2. Random noise criteria would be used for impulse noise that is random in nature.

5.3 Data

Signal to noise ratio (SNR) can be used to determine the performance of modems used for data transmission. Curves of SNR (noise defined as the total of all spurious products) versus bit error rate (BER) supplied in the instruction manuals for the modems can be used to determine whether or not the required BER will be achieved. In the absence of BER versus SNR data, few modems operate acceptably at a 12 dB SNR, while most can tolerate an SNR of 20 dB or better. Satisfactory operation also requires that line conditioning for group delay be correct; refer to the equipment instruction manual for line conditioning or other requirements concerning line equalization or conditioning. Special meters are available for measurement of waveform distortion on teletype circuits, satisfactory operation requires that specified distortion levels be met.

5.4 Radar

Frequently one is faced with the problem of calculating the level of interference that would occur if a radar were located at a given site, or calculating the level of interference that would occur at an existing site if a new source of interference were added to the environment. A sample procedure for such calculations is presented in this section:

(a) The source of interference must exceed the receiver detection threshold to affect performance, this is typically +5 dB above the receiver noise level. The receiver noise level is the noise figure plus 10 Log (4 KTB) dBW $K = 1.38 \times 10^{-23}$, $T = 290$, B = bandwidth in hertz.

(b) When the interference is sufficient to severely affect performance, coupling will also be via side lobes. Side lobe gain is approximated as 0 dB relative to an isotropic radiator.

(c) Waveguide losses are neglected and a 5 dB noise figure assumed (worst case analysis). If the victim radar system is not on the same frequency as the source of interference, then additional allowance must be made for the off-channel rejection of the victim radar receiver.

Example:

Another government agency proposed to install equipment operating on 2700 MHz that would produce an estimated median field strength of 20 uV/m (main lobe coupling) at a nearby FAA ASR. A transportable system was operated at the proposed site and actual measurements at the FAA ASR determined that terrain shielding was not as good as expected, the measured median field strength was 100 uV/m (main lobe). The proposed system would have a main lobe antenna gain of 34 dB (side lobes taken to be 0 dB, item (b) above). The measured median field strength of 100 uV/m, not the estimated value of

20 uV/m, is the one used in the performance calculation (loss predictions for long paths can be in error as much as ± 20 dB). Then a calculation is made to determine the level of interference relative to the detection threshold:

Interference (main lobe)=100uV/m	-106 dBW/m^2
Convert to interference from sidelobes	-34 dB *
Convert median to maximum signal level	+12 dB
Receiver side lobe aperture (0 dB gain)	-30 dB **
Subtract receiver detection threshold	+119 dBW***
Interference relative to threshold:	-39 dB

***Receiver detection threshold, -119 dBW, is 5 dB above noise, 8 MHz bandwidth, 5 dB noise figure.

$$**\text{Aperture} = \frac{G\lambda^2}{4\pi} = \frac{.0123}{4\pi} = .000982 \text{ m}^2$$

$$10\text{Log}.000982 = -30 \text{ dB}$$

*Only if interference source couples via side lobes.

This value is for side lobe to side lobe coupling. The interfering signal level would have to be increased 39 dB to obliterate the FAA ASR display. Note that if the interfering system were operated with the main lobe fixed in the direction of the FAA ASR that the margin would be only -5 dB, and serious interference might result.

The method given in the above example provides a good first cut estimate of whether or not a potential interference problem exists. If it does exist, a test generator simulating the source of interference should be used to determine the exact signal level that can be tolerated. In the case of continuous wave interference, the victim receiver may not tolerate much more interference than that assumed in the example. In the case of pulsed sources of interference, with the victim receiver equipped with digital tracking, the only concern may be burn out of the receiver front-end. If more detailed paper calculations are attempted, care should be taken to include all relevant factors. Some of the factors that must be considered are listed below (analysis varies with the design of the radar system and therefore is not given):

(1) required probability of target detection during a scan, the blip/scan ratio (e.g. .75).

(2) range of worst case target, the maximum range (e.g. 50 nautical miles).

(3) -3 dB antenna beamwidth (e.g. 2 degrees).

(4) pulse width (e.g. 1.0 uSec.).

(5) pulse repetition frequency, PRF (e.g. 1 kHz).

(6) antenna scan rate (e.g. 15 revolutions per minute, RPM).

(7) wavelength (e.g. .09 meter).

(8) transmitter peak power, RMS pulse power (e.g. 400 KW).

(9) antenna gain (e.g. 32 dB).

(10) receiver bandwidth (e.g. 1 MHz).

(11) receiver noise figure (e.g. 5 dB).

(12) range under free space propagation conditions, it is assumed that correspondingly larger targets would be required for satisfactory operation at greater ranges (e.g. 1 square meter target at 20 nautical miles, 4 square meters at 28 nmi., etc.).

(13) receiver noise Rayleigh distributed.

(14) fluctuation in target return signal strength Rayleigh distributed from scan to scan, correlated during a scan.

(15) maximum false targets per scan (e.g. 40).

(16) mode of operation such as normal, moving target detection, or secondary radar (e.g. moving target detection)

(17) whether interference will be pulsed or continuous wave, random or coherent (e.g. random continuous wave).

(18) losses and gains due to radar receiver processing (e.g. 5 dB)

(19) radar losses such as atmospheric absorption, circulators, sensitivity-time characteristic, rotary joint, waveguide, and azimuth straddle (e.g. 4.5 dB).

(20) losses in the transmitter of the source of interference (e.g. 3 dB).

(21) the possibility of modifying factors such as PRF or transmitter power to reduce interference.

(22) propagation via reflection off aircraft may dominate over propagation along the surface of the earth (e.g. sites 80 statute miles apart).

(23) garbling of secondary radar returns must be considered

5.5 NAVAIDS

Interference to reception from a navigational aid (NAVAID) tends to produce an unstable course reading. This is because the velocity of aircraft causes rapid variations in the relative strengths of the desired and interfering signals. This problem is usually averted by proper frequency engineering (see Order 6050.5A), and may be eliminated by a frequency change.

A serious problem exists with NAVAIDS interfering with their own transmissions as a result of reflections off terrain features. Diffraction models have been developed that simulate the field distortions produced by propagation through large objects such as buildings. The problem with diffraction models is that it is already known that large obstructions cause course errors and what is needed is removal of the obstruction or relocation of the NAVAID. Computer models also have been developed that analyze the effects of multipath when inputs are provided concerning the cross-section, complex impedance and orientation of reflecting objects. The problem with these models is that actual measurements must be made to determine input values for the model, eliminating the objective of avoiding field measurements. An effective (and expensive) method of site evaluation is the use of a transportable NAVAID and flight check aircraft. This approach does not positively identify the sources of course errors such as fences, hills, water towers, buildings, trees, etc. One method of evaluating the intensity of reflections off various terrain features is by the use of a multipath probe (see Section 4.7 and Appendix D). Such an evaluation might verify that strong reflections are being propagated off a fence but not a grove of trees, hence saving the expense of removing the grove of trees. Multipath probes may have insufficient sensitivity if omnidirectional antennas are used (required for use in aircraft) and there may be difficulty in correlating the time delay of various multipath components with various terrain features. The best alternative usually is to adhere to established siting criteria and thereby avoid most multipath problems.

5.6 <u>Automated Site Analysis</u>

There are numerous computer programs available for producing outputs such as coverage charts, analyzing potential equipment interactions at a site, examining other systems in the environment, selecting frequencies, selecting an optimal site, etc. Some can be run on hand-held calculators, others require large scale computers.
See Chapter 5, Computer Analysis Aids, of Order 6050.17B, Frequency Management Engineering Principles, VHF/UHF/SHF Communications Links for a brief description of some of these aids; additional programs exist for determining the coupling between antennas on an aircraft, modeling ATCRBS performance, etc. It is important to recognize the limitations of such programs, such as the lack of man-made objects in a terrain file, so that best use can be made of the outputs.

6. ELECTROMAGNETIC COMPATIBILITY

6.1 Scope

This chapter includes interference criteria, procedures for measuring selectivity and emission spectrum, methods for locating sources of interference, and methods for resolving interference.

6.2 Receiver Selectivity

A receiver's response to interfering signals outside the channel it is tuned to is a function of many design parameters. Two signal intermodulation products can be eliminated by proper selection of operating frequencies. In general, the minimum channel spacing that can be used is limited by frequency stability and the ability of the receiver to reject single off-channel signals. This is the reason that receiver selectivity characteristics are found in properly prepared receiver instruction manuals. Since selectivity characteristics are essential to an evaluation of equipment performance, measured selectivity characteristics are required in Order 6050.19C, Radio Frequency Spectrum Utilization and Management. The suggested procedure is as follows:

(a) Off-channel signal levels shall be recorded in dBW from the noise level to a level 80 dB above the minimum usable on-channel signal level. The minimum usable on-channel signal level is defined as the minimum level that provides an acceptable ratio of desired signal to undesired products in the absence of an off-channel interfering signal.

(b) Examine frequencies from on-channel to points above and below the on-channel frequency by an amount equal to the width of the allocated frequency band the equipment will operate in.

(c) Selectivity shall be determined by the application of a fully modulated on-channel signal at a level 3 dB above the minimum usable on-channel signal level and then recording the off-channel signal levels that degrade the desired signal to undesired products ratio to the minimum acceptable ratio. Note that this procedure provides a combined RF-IF selectivity measurement. An appropriate modulation of the off-channel signal shall be used.

(d) The off-channel signal levels required to cause the degradation described in Item (c) above shall be recorded for a single off-channel signal. Also, the off-channel levels required to cause the degradation described in Item (c) above shall be recorded for two equal amplitude off-channel signals spaced so as to produce an on-channel third order intermodulation product.

6.3 Transmitter Emission Spectrum

In properly designed transmitters there is a sharp drop (down to insignificant levels) in emissions at frequencies removed from the carrier by more than the maximum modulating frequency. Harmonics of the carrier also are at very low levels. Exceptions to this rule occur when broadband operation, small physical size, or minimum cost are the design objectives. If a plot of the emission spectrum is not available, it may be necessary to measure the spectrum. A procedure for this follows:

(a) Record emission levels at the transmitter output, in dBW, from the peak carrier level down to a level 80 dB below the peak carrier level.

(b) A 1 kHz measurement bandwidth shall be used.

(c) Examine frequencies from the on-channel frequency to points above and below the on-channel frequency by an amount equal to the width of the allocated frequency band the equipment will operate in. Also examine the second and third harmonic of the on-channel frequency.

(d) Record the emission spectrum without the application of an external signal to the transmitter output. Also record the level of the third order intermodulation products created by the application of external off-channel signals at a level 20 dB below the peak carrier level (this applies to non-pulsed systems only). The transmitter shall be fully modulated for these tests.

6.4 Frequency-Distance Criteria

The known transmitter emission spectrum, receiver selectivity characteristics (including frequency tolerance), and free-space propagation losses can be converted into frequency-distance criteria. This criteria consists of a plot of the distance an interfering transmitter must be separated from a victim receiver versus the frequency separation between the receiver and the transmitter. At one extreme the transmitter and receiver can use the same transmission line with a frequency separation as low as perhaps 150% of the emission bandwidth. At the other extreme terrain shielding must be used to provide sufficient isolation for operating the interfering transmitter on the same channel as the receiver; anomolous propagation conditions are likely to eliminate such isolation on a periodic basis. A serious problem with frequency-distance criteria is the large amount of data required to accommodate variations among the equipment in use (data for each possible receiver-transmitter combination. Although frequency-distance criteria provide good guidance prior to installation of a facility, the requirement for accuracy necessitates the use of actual signal level measurements to resolve an interference complaint.

6.5 Degradation Criteria

As a rule, any interference that raises the level of spurious products intermixed with a desired signal is considered to be harmful interference. Frequently considerable amounts of harmful interference are tolerated, and the associated reduction in reliability is accepted. Such cases occur when it is impractical to override the interference (such as noise from lightning), when it is impractical to prevent attempts at simultaneous use of a shared circuit (such as mobile maintenance communications), or when it is impractical to modify terrain (such as terrain reflections causing a NAVAID to interfere with itself).

Another important factor affecting a desired signal is outages. When a circuit or facility fails, reliance is placed upon standby circuits or alternate facilites. Records are kept for various FAA circuits and facilities concerning their availability (e.g., a circuit might have been operational 98% of time during the past month). On occasion it possible to avoid interference by the use of standby facilities, in cases where the primary facility is being subjected to interference but not the standby.

Obviously, the desirable level of performance degradation by interference is zero. As a practical matter, this goal can be approached in facilities such as carefully designed point-to-point microwave communications links, and cannot be achieved in facilities such as those used for randomly accessed mobile communications. The "zero level" of interference is represented by criteria setting interference equal to the victim receiver's noise level. These values are given in Appendix A and provide a good indication of the relative vulnerability of various facilities. They represent the point at which degradation will begin to occur, and do not represent the maximum tolerable level of interference, which can be far higher. Any source of on-channel interference producing receiver input power levels below those contained in Appendix A will not produce an interference problem. The significance of higher interfering levels will depend upon the particular facilities.

6.6 Locating Interference

Various sources of environmental noise tend to obscure a source of interference. When the interference spectrum is noiselike in nature, isolation of individual noise sources becomes increasingly difficult as altitude increases. In a metropolitan area, the combined manmade radio noise interference sources produce a noise smog. The interference may arrive via power line conduction, coupling from control/audio/ transmission lines or coupled directly into the IF in a poorly shielded receiver. Combinations of spectrum characteristics, voice broadcast identifications, directional antenna, signal magnitudes, times of operation, and receiver response information, are used to identify the source. The interference is localized by flight check aircraft or ground radio frequency measurements vehicle, and may finally be located by the investigator carrying a portable receiver. A wide variety of equipment is available and is selected according to frequency, physical limitations, availability, and other environmental problems. When various noise spectrums in an area do not carry easily identifiable characteristics it is technically advantageous to turn suspected sources off and on for identification of individual contributors to the total noise seen by the aircraft. In power shut down procedures one must actually see the switch thrown or use a transceiver with carefully prearranged signals to avoid misleading conclusions accompanying a simultaneous co-incidental removal of interference due to another cause. A local knowledge of the spectrum users coupled with environment monitoring from time to time aid in locating objectionable noise sources quickly. Due to the difficulty in correlating ground radiation measurements with interference experienced by aircraft, flight check may be necessary to determine if corrective action has removed the problem.

(a) Direction Finding.

Directional characteristics of antennas are used to establish a signal source bearing. Successive bearings from different locations help to triangulate and "pin point" the source location. Individual bearings are complicated by signal reflections and shielding in the presence of large buildings or terrain. Location errors due to bearing ambiguities are minimized by successive measurements from varying locations. In a large city when reflection, absorption, and shielding problems render directional antenna efforts ineffective, signal magnitude bracketing techniques are useful. In this method a street map is handy to systematically record relative signal strengths in the area. Measurements taken from street intersections are particularly meaningful but pose an operational problem in a mobile van in the presence of heavy traffic. The antenna should be oriented for maximum signal; however, for the first broad survey attempt a whip antenna projecting through a car side window may be employed with the driver noting portable receiver audio or "S" meter levels. When the source is many stories high in a tall building, the radiation signal strength may be weak in the street below, but relatively strong a block or two away. After bracketing attempts to centralize the likely building or two, the search may end with the investigator riding the elevators while monitoring a hand held receiver to locate the floor and room. When permission to enter becomes a problem, the FCC or other proper authority should be involved. Inconspicuous measurement efforts minimize the chance of the interference device operator closing down his machine to avoid detection. The operators often spread the word when they become aware of a search effort so that location efforts are then delayed until operation resumes.

(b) Direction Finding Antennas.

Choice of the directional loop, whip, dipole, or horn antenna, for example, is dependent on the frequency. Physical dmensions vary inversely with frequency over the range from low frequency to microwave portion of the spectrum and are an important factor in mobile operations.

(c) The Loop Antenna.

Use of the loop antenna at lower frequencies permits a directional capability using an antenna of much smaller physical size than a dipole when sufficient signal strength is available to offset the loss in gain. The sharpest bearing indication is obtained when a plane through the loop is normal (at right angles) to the source direction; however, if the source is too weak the stronger signal obtained by aligning a plane through the loop where the signal bearing indication makes possible a broad bearing indication. Unless a sensing antenna is employed any given bearing obtained may be the desired one or the reciprocal (180°). The intersection of a second bearing from another location resolves this problem.

Inclusion of a matching section extends the loop frequency range over a wider band. Presence of a sky wave (or other source of multipath) in addition to the ground wave decreases the reliability of the loop bearing measurements compared to those obtained with a single propagation path.

(d) Horizontal Dipoles.

Half-wave dipole antennas are useful over a frequency range from about 3 MHz to about 1 GHz. Below 30 MHz physical dimensions are generally too large for mobile operations; and conversely, above 1 GHz they become to small electrically. These antennas are furnished with connecting cables and calibrating data to match a particular radio frequency interference receiver. The maximum signal is obtained when a line ghrough the dipole elements is "broadside" (normal) to the signal source bearing. The minimum reception is obtained when the dipole elements are aligned with the source bearing.

(e) Whip Antenna.

The whip antenna is useful at VHF frequencies and on portable receivers because of its physical dimensions. Maximum signal is obtained when the antenna is aligned for correct signal polarization and broadside to the source bearing. A telescoping whip antenna is handy on portable receivers when the investigation is being conducted on foot. Compactness becomes important when climbing poles and towers, or working in other areas with difficult physical access problems. The accuracy of the bearing obtained by using the null in the antenna pattern usually is poor.

(f) Horn and Parabolic Antennas.

Above 1 GHz the physical dimensions, high gain, and highly directional characteristics of the horn and parabolic type antennas make them readily adaptable to signal source location activities. Polarization of the incoming signal is determined by rotating the antenna for maximum detection amplitude and noting the horn slot alignment (the polarization is in a direction across the narrow slot dimension).

(g) Identification of Interference

Measurements associated with interference identification efforts are made in the presence of environmental noise from natural and manmade origins. A facility may be subject to interference from a number of sources, some of which become noticed only during investigation of a more serious complaint. Some sources, such as vehicle ignition noise, may be transient and unlocatable.

(h) Natural Radio Noise.

Natural radio noise distributions vary over several decades of frequency more or less uniformly. These are a function of geographical location, frequency, time of day (diurnal effects) and season, sun spot cycle, and other factors. Atmospheric noise (thunderstorms, etc.) is predominant below 20 or 30 MHz in geographical locations where manmade noise is low. Galactic sources are important above 30 MHz up to perhaps 1 GHz when high gain antennas are used.

(i) Manmade Radio Noise.

Where the manmade noise level is high, it is likely to overshadow natural noise over a frequency range of a few Hz to perhaps 1 GHz. In these areas the power line noise contributes heavily up to about 1 MHz and automotive ignition becomes increasingly important contributor with frequency up through the high frequency band. After the frequency is reached where maximum ignition interference is experienced its effects begin to decrease so that at 160 MHz and 450 MHz the amplitude falls below that experienced at 50 MHz by 7 and 12 dB, respectively. Receiver noise increases with frequency and becomes important whenever it approaches the combined external noise level so that efforts to reduce it become increasingly beneficial as the frequency increases above several hundred MHz. Certain manmade, noise-like signals add to and are difficult to distinguish from the composite environmental noise (particularly around the urban areas of the country). Other manmade interference may be isolated due to emission spectrum, transmission interval, frequency instability, audio characteristics, frequency band, type of industry in the environment, or other pertinent feature peculiar to the device. Interference may come from licensed transmitter spurious emissions or from unlicensed or "type certificated" emitters such as are covered by Parts 15 and 18 of the FCC Rules and Regulations.

(j) Identification by Audio Intelligence.

Interfering signals and their spurious emissions contain characteristic audio sounds which augment other information (amplitude, bearing, locality, etc.) in a complementary manner leading to source identification. In the case of voice modulation this may be in the form of call signs, type of operation, and place names.

The monitoring receiver response becomes important to the analysis. For example a dielectric heater used to make seams in plastic products manufacture commonly exhibits a raw 60 or 120 Hz AC audio buzz and the carrier frequency drifts considerable during the short intervals of power application. The 5 second pulse drifts through the receiver 50 kHz bandwidth rapidly and is reported as a one second pulse. The investigator uses a 150 kHz bandwidth receiver and hears it for 3 seconds. Communications between the investigator and operator in the search effort is complicated by this detail, but is aided by observing that the approximate interval between pulses is the same.

(k) Identification by Measurements and Evaluation.

During search efforts a similar detection mode on the RFI receiver is selected to compare with the receiver being interfered with; however, in some cases the same receiver or type must be used to recognize the interference. The mode of detection for formally recorded amplitudes may also be chosen to be most useful in comparing the results of several investigators or for the most suitable presentation to the FCC. The quasi-peak mode is recognized internationally for evaluating the degradation caused by impulse noise such as auto ignition. The charge and discharge standards are different in various countries. For spectrum signatures of rapidly varying waveforms a variable charge to discharge time combination switch is advantageous, as for example, when direct peak mode is not available.

6.7 Resolving Interference.

Action taken to correct interference problems becomes a function of the type facility (safety, entertainment, etc.), the organizations involved, the priority given to the operation, technical capability, and economic feasibility. The following examples serve to illustrate these points:

(a) Dielectric Heater Example.

A small plastic products firm has a dielectric seamer causing interference to a VOR. They may find it more economical to provide proper shielding and filtering for the individual machine than to shield the room. A larger company having many machines finds it practical to shield the entire building.

(b) High Power FM Interference Example.

A VOR is reported as being interfered with by a FM broadcast station. The FCC field office is contacted by the RFMO and a flight/ground mobile location/measurement effort, etc. arranged. Only if the interference persists after reducing the FM spurious emission by filtering, etc., to within tolerance should a VOR frequency change be resorted to.

(c) Radar Interference Example.

A radar transmitter interfers with certain TV receiver models and not with others. The interference is being coupled into the IF stages because of poor receiver shielding.

(d) ARSR Interference Example.

When interference complaints are received by the FAA, the agency may investigate the problem to maintain good public relations even though, initially, the technical aspects make liability appear unlikely. An example of this occurred in the New York City area when TV viewers observed alternate black and white bars a couple of inches wide slanting horizontally upward across the receiver screen which obliterated the picture at various time intervals. The complaint alluded to the problem starting when an air route surveillance radar (ARSR) was placed in operation.

The regional Frequency Management Officer (RFMO) dispatched a radio frequency measurements mobile unit to investigate. The interference was noted to occur in three short bursts with a short interval between each and a longer interval between groups. When the RFI receiver was tuned to the approximate IF frequency of the sets being interfered with, groups of three audio tones in various pitch combinations and sequences were heard typical of "call services." A direction finding search localized an area of several city blocks but failed to pinpoint a building. A call to the FCC describing emission characteristics and approximate location resulted in license information for a remotely operated (unattended transmitter) service on top of a tall building within this area. The site location explained the unreliable direction finding attempts at street level dut to shielding/low angle path problem in the immediate building vicinity. The mobile unit repreated the signals on another frequency to the mobile van portable transceiver carried into the TV shop which had been coordinating customer complaints so the owner could see the timing coincidence of the tones and the interfering TV screen bars. While the FAA personnel believed early in the search that there was no correlation between the ARSR and the TV problem, public confidence in their technical resources was enhanced by locating the source. In this instance FAA personnel had been on a wild goose chase. The FCC ruled that the licensed transmitter was operating within authorized limits; and, since the cause was due to poor receiver design, the "fix" decisions were left to the individual owners and repairman.

(e) Radar Interference to Radio Astronomy.

Because of the extreme antenna gains and receiver sensitivities employed in radio astronomy work additional effort is required to filter the FAA radar spectrums in the vicinity of these installations. The interference involved the Harvard University Observatory and the ARSR at Fort Heath on the Observatory frequency 420.4 MHz. The RFMO conducted tests using the RFI van to measure the electromagnetic spectrum before and after filter installation. Installation of the filter resolved the complaint.

(f) Control Circuit Interference.

Cases of defective thermostats at the site (or in one case on a farmer's heating pad), faulty power distribution arcs, and other radio noise sources have been reported as causing PPI strobes.

(g) TV and FM Receiver Radiation.

A case of localizer interference on 111.7 MHz in the FAA Eastern Region resulted from excessive receiver oscillator radiation. Oscillator radiation from an FM stereo receiver tuned to 101.5 (101.5 $\pm$ 10.2 IF = 111.7 osc.) contributed part of the interference; however, a TV receiver was located which could be detected on the ground for two miles and in the air for 22 miles. This set had an IF varying between 43 and 45 MHz with fine tuning causing the high frequency oscillator to "bracket" 111.7 MHz when tuned to channel 4 (66-72 MHz) TV.

(h) Ignition Interference to Localizer.

Ignition noise interference to an ILS localizer resulted from a six cylinder engine running at 1500 RPM at a cement mix plant. This was difficult to locate because it resembles similar interference introduced by other gas engines in this metropolitan environment and was finally located by a locator receiver mounted in a mobile unit so that the 150 cycle per second interference component product was detected through crosspointer instrument deflection. The shielding was replaced on the engine, and the problem was eliminated.

(i) Dielectric Heaters.

Dielectric heaters (such as the fourth harmonic of 27.12 MHz) are associated with the plastics (seaming and molding) and plywood (glue drying) industries. Resolved by shielding.

(j) High Power FM/TV

Cases involving FM and TV broadcast stations are the combined result of strong field intensities and intermodulation effects. These are aggravated by the use of receivers with an inadequate dynamic range (the receiver overloads).

(k) Power Line Noise.

Noise sources such as power substations and distribution systems cause decreased signal to noise conditions which are a problem in marginal service areas.

(l) Incidental Radiating Devices.

The arc or magnetic field resulting from circuit electrical transients creates interference producing characteristic audio noises (buzz, click, snap, crackle, pop, squeal, whine) in receiver or other electronic system outputs. Devices in this category include auto ignition systems, motor/generator commutators, bells, buzzers, semi-conductor voltage regulator/rectifier, oil furnace igniters, small electrical appliances, electronic toys, and power distribution apparatus. Cases involving these devices should be reported to Washington headquarters for forwarding to the FCC so problems can be corrected in future units at point of manufacture.

New devices are constantly being introduced to the environment. Interference comes form a variety of devices such as oscillators, silicon controlled rectifiers, integrated circuits and relays. The investigator may be involved in the "fix" in some cases to eliminate the problem in government equipment; however, caution should be exercised as to involvement with modification of private equipment which is not the government's responsibility. Corrective attempts should start by determining that operation is normal for the device as manufactured (are existing noise filters malfunctioning; does the commutator need turning; or the brushes need to be replaced?). Some devices have optional noise circuitry available from the manufacturer which should be used. It is possible to damage equipment through improper application of noise filter components. The personnel and fire hazard potentials of any circuit modification may require installation of parts in a metal box, for example.

(m) Super-regenerative Receivers.

Super-regenerative receivers operating in the 225 to 400 MHz band are used in devices such as garage door openers (GDO) and burglar alarms. Although strict limits on emissions preclude problems with newer equipment, some older equipment (lacking an RF stage to isolate the antenna from the regenerative amplifier) is still in service. Emissions can easily cover a range as great as $\underline{+}10\%$ of the operating frequency. Location of offending sets with a mobile RFI van in a residential district is complicated by the presence of overhead power service which conducts the missions along the lines in some cases for a considerable distance until filtered out by the power distribution transformer, for example. Commonly the noise-like audio characteristic is detected as the receiver is tuned across the band within a few hundred feet of the GDO. The amplitude increases and decreases rapidly (fluctuates) in a somewhat recurring fashion (apparently due to power lines overhead) as the vehicle approaches the vicinity of the door opener. The alert operator makes use of visible clues to augment measurement information and may note the antenna and bottom of opener equipment above an open door or the absence of a handle on a closed door. The 180 degree dipole bearing and reflection ambiguities are partially resolved by taking multiple measurements in different locations.

Another example of super-regenerative receiver emission is a device available under several manufactured names and that converts VOR and VHF air/ground communications signals down to the AM broadcast band for use with a transistorized AM receiver tuned to an unused portion of the broadcast band. This type of set or converter has been found to open air traffic control (ATC) tower receiver squelches from a distance of several hundred feet. The relatively low amplitude of the devices largely limits the hazard to use around airports or other ATC supporting facilities; however, units also offer sufficient interference to VOR receivers found in the smaller aircraft types to cause large bearing errors when operated on board or in the close vicinity. Location of these devices is often very difficult since by the time measuring equipment is brought to the scene, the instrument causing the interference has departed. Popularity of the super-regenerative receiver is partially due to the high sensitivity of a one stage circuit and because its wide bandwidth offsets any frequency instability problems. Also, it is easily retuned.

(n) Industrial, Scientific, and Medical Devices (ISM).

ISM operating provisions are contained in the FCC rules and Regulations, Part 18. Industrial categories include glue drying machines used in plywood manufacture, dielectric heaters used in plastic products manufacturing for seams and molding, RF ovens for cooking and baking, induction heaters for metal heating, and other purposes where RF energy is created intentionally for a manufacturing process. Medical equipment includes diathermy, x-ray, and ultra-sonic equipment. Certain other scientific and miscellaneous equipment is associated with biological, physical, technical, ionization of gases, and other research projects.

When interference is caused to air navigation services, operation of the device must cease immediately upon notice from the FCC and not be resumed again without permission of the engineer in charge following corrective effort. The operating power of industrial radiating devices is often many kilowatts in the authorized ISM bands so that interference from harmonics and spurious emissions can be caused to radio navigation services many miles from the source. Some examples are: The ninth harmonic of 13.56 MHz falls in the VHF air/ground band; the fourth and fifth harmonics of 27.12 MHz (heavily used by ISM)in the localizer and VHF air/ground communications bands, respectively; the third harmonic of the 40.68 MHz band falls in the VHF air/ground band. Past cases on record show that when interference due to dielectric heating equipment used in plastics manufacturing "loft" operations was located, these operators would close down the business and move the machines to a new site where the interference shows up again. Operating cycles of dielectric heaters may vary from one second to several seconds on larger manufacturing work (long plastic seams); however, if this is repeated several times a minute circuit degradation/operator disturbance may be considerable. It is noted that a long heating pulse which is rapidly changing frequency may only be within the bandpass of a narrowband receiver for a second or less as it passes through, giving the false impression that it was a short pulse.

When documenting an interference case notes should be taken regarding the duration of power pulses, interval between pulses, hours of the day,noticeable quiet times, (generally, any information which would be helpful in identifying the source or type of operation). Out of tolerance conditions found producing interference to radio navigation services should be reported to the FCC. The industrial operator must immediately cease operation of the device upon instruction from the FCC until the condition is corrected. The FAA measurement operation should be well documented for FCC action (it may be used in court) because of the economic and public relations impact of shutting off various types of industrial equipment. The interference investigator should continually keep in mind the legal implications involved with regard to trespassing on industrial plant or other private property for measurement purposes so as to properly assess the right time to involve the FCC. Diplomacy must be exercised when contacting industrial personnel with respect to interference complaints as to the course of action to identify and correct problems. When a large number of radiating machines are contained under one roof only one or a few may be objectionable. In this case an interference description, spectrum plot, duty cycle, and activity times, may, when conveyed to the plant manager, help to identify the right machine so that only a small portion of the operation need be curtailed for positive identification. When a large number of different signal characteristics are present and the plant has already been shielded with screening or foil it may be that the access doors leading to the equipment area are being opened during equipment operation or improperly bonded.

(o) Clustered Equipment.

The advantage of a high mountain top or building roof for extending the radio service range attracts many users of the spectrum to locate equipment in close proximity. A large number of transmitters and receivers using closely spaced antennas produce special problems.Electromagnetic incompatibilities may include spurious transmitter emissions, receiver overload, and the generation of intermodulation products. An antenna may be oriented in different horizontal planes, azimuth bearings, and polarization so that the combined effects become difficult to describe and analyze. While exact treatment of the physical aspects and operating frequencies is cumbersome, a review of these considerations assists the site survey. For this reason, site survey activities in connection with interference should include photographs of antenna installations, charts of antenna locations, types of equipment, and conversations with other local operators in addition to spectrum survey measurement. Thoughtful use of the supplementary material may reduce or eliminate the need for elaborate spectrum monitoring survey procedures.

APPENDIX A

NOMINAL EQUIPMENT CHARACTERISTICS

NOMENCLATURE	EMISSION BANDWIDTH*	POWER (WATTS)	ANTENNA POLARIZATION	ANTENNA GAIN	RECEIVER NOISE LEVEL(dBW)
OMEGA	.1	20K	V	L	-174
LORAN C	20	300K to 1.8M	V	L	-151
L/MF Radio Beacon:					
LOM/HSAB	6	150 to 400	V	L	-156
MH/H/HH/RLR	2.04	100 to 4K	VH	L	-161
	6	25 to 1K	VH	L	-156
MHW/HW/LOM/LMM	1.12	25	V	L	-164
	2.04	100 to 600	V	L	-161
HF RTTY	1.01	1K	VH	M	-164
HF SSB	3	1K to 10K	VH	M	-159
HF SSB,"CB"	3	5	V	L	-159
HF AM,"CB"	6	5	V	L	-159
75MHz Marker:					
OM	.8	4	H	L	-165
MM	2.6	4	H	L	-160
IM,MM	6	2.5	H	L	-156
VHF Localizer:					
V-ring	6	9	H	M	-156
null reference	2.04	15	H	M	-161
8 loop	6	200	H	L	-156
waveguide	14	15	H	M	-153
VOR	21	100 to 200	H	L	-151
VHF A-G Comm.	6	10 to 50	V	L	-156
VHF Links	16 to 190	10 to 150	H	M	-152 to -141
VHF Mobile	16	4 to 100	V	L	-152
Glide slope:					
null reference	.3	1 to 25	H	M	-169
capture effect	8.3	2 to 25	H	M	-155
UHF A-G Comm.	6	10 to 100	V	L	-156
UHF Links	20 to 400	10 to 90	VH	M	-151 to -138
UHF Mobile	6	5	V	L	-156
UHF "Skyphone"	16	20	V	L	-152
UHF Mobile	20	35 to 90	V	L	-151

NOMINAL EQUIPMENT CHARACTERISTICS

NOMENCLATURE	EMISSION BANDWIDTH*	POWER (WATTS)	ANTENNA POLARIZATION	ANTENNA GAIN	RECEIVER NOISE LEVEL (dBW)
TACAN/DME	650	80 to 15K	V	L	-136
ATCRBS	M6	300 to 10K	V	H	-126
Mode S/TCAS	M6	1K	V	H	-126
ARSR	M5 to M10	1M to 10M	VH	H	-127 to -124
L Band Links	M5	5	V	M	-127
ASR	M1 to M10	400K to 5M	VH	H	-134 to -124
LSR	M1	150K	V	H	-134
MLS	35	5	VH	M	-149
ARSR Links	M20	.15	VH	H	-121
ASR Links	M27	5	VH	H	-120
Brite Links	M27	.2	V	H	-120
ASDE	M200	50K	VH	H	-111

* Kilohertz unless preceded by M, M is megahertz

KEY: Antenna polarization: V = vertical; H = horizontal; VH = circular, or either vertical or horizontal

Antenna gain: L = 0 to 12 dB
M = 12 to 25 dB
H = 25 to 45 dB

APPENDIX B

BAND ALLOCATIONS

BAND	PRIMARY USAGE
9 - 14 KHz	OMEGA
90 - 110.0 KHz	LORAN "C"
190 - 490 KHz	Aeronautical Radio Beacons (NDB's)
510 - 535 KHz	Aeronautical Radio Beacons (NDB's)
1705 - 1750 KHz	Aeronautical Radio Beacons (NDB's)
2850 - 3025 KHz	Air/Ground (R)
3025 - 3155 KHz	Air/Ground (OR)
3400 - 3500 KHz	Air/Ground (R)
4650 - 4700 KHz	Air/Ground (R)
4700 - 4750 KHz	Air/Ground (OR)
5450 - 5680 KHz	Air/Ground (R)
5680 - 5730 KHz	Air/Ground (OR)
6525 - 6685 KHz	Air/Ground (R)
6685 - 6765 KHz	Air/Ground (OR)
8815 - 8965 KHz	Air/Ground (R)
8965 - 9040 KHz	Air/Ground (OR)
10005 - 10100 KHz	Air/Ground (R)
11175 - 11275 KHz	Air/Ground (OR)
11275 - 11400 KHz	Air/Ground (R)
13200 - 13260 KHz	Air/Ground (OR)
13260 - 13360 KHz	Air/Ground (R)
15010 - 15100 KHz	Air/Ground (OR)
17900 - 17970 KHz	Air/Ground (R)

NOTE:
R- On Route
OR- Off Route

BAND	PRIMARY USAGE
17970 - 18030 KHz	Air/Ground (OR)
21870 - 21924 KHz	Point-to-Point Communications
21924 - 22000 KHz	Air/Ground (R)
23200 - 23350 KHz	Air/Ground (OR)
74.8 - 75.2 MHz	Marker Beacons
108 - 117.975 MHz	VOR and Localizer
117.975 - 136 MHz (121.5)	Air/Ground Communications (R) (Emergency)
136.0 - 137.0 MHz	Air/Ground Communications (R)
162.0 - 174.0 MHz	Fixed and Land Mobile
225 - 400 MHz (243)	Air/Ground Communications, Navigation (Emergency)
328.6 - 335.4 MHz	Glide Slope
406 - 420 MHz	Fixed and Land Mobile
960 - 1215 MHz (1030/1090)	TACAN/DME, ATCRBS/Mode S (ATCRBS/Mode S Beacons) TCAS
1227.6	GPS(Radionavigation Satellite)
1240 - 1370 MHz	ARSR
1435 - 1535 MHz	Telemetering
1544 - 1660.5 MHz	Radio Altimeters, Aeronautical Mobile Satellite (R) NAVSTAR/GPS(1575.42 MHz)
2310 - 2390 MHz	Telemetering
2700 - 2900 MHz	Airport Surveillance Radar
3500 - 3700 MHz	Limited Surveillance Radar (Planned)
4200 - 4400 MHz	Radio Altimeters
5000 - 5250 MHz	Microwave Landing System

BAND	PRIMARY USAGE
5350 - 5470 MHz	Airborne Weather Radar
7115 - 7250 MHz	Radar Microwave Link
7300 - 7975 MHz	Radar Microwave Link
8750 - 8850 MHz	Airborne Doppler Radar
9000 - 9200 MHz	Precision Approach Radar (PAR)
9300 - 9320 MHz	Aeronautical Radar Beacons
9320 - 9500 MHz	Airborne Weather Radar
13.25 - 13.4 GHz	Airborne Doppler Radar (Military)
14.0 - 14.3 GHz	Airport Surface Detection Equipment ASDE System
14.4 - 15.35 GHZ	Television Microwave Link (BRITE)
15.4 - 15.7 GHZ	Airborne Weather Radar
15.7 - 16.2 GHz (Primary)	Airport Surface Detection Equipment ASDE III System
16.2 - 17.7 GHz (Secondary)	Airport Surface Detection Equipment ASDE III System
24.25 - 25.25 GHz	Airport Surface Detection Equipment ASDE System II
31.8 - 33.4 GHz	Radionavigation (future use)
43.5 - 47 GHz	Radionavigation & Sat. (future use)
45.5 - 47 GHz	Radionavigation, Radionavigation Satellite, Satellite (future use)
66 - 71 GHz	Mobile, Mobile - Satellite, Radionavigation, Radionavugation Satellite (future use)
95 - 100 GHz	
134 - 142 GHz	
190 - 200 GHz	
252 - 265 GHz	

Note: Allocation tables are subject to frequent changes. This table reflects planned changes as of August 1982.

APPENDIX C

MISCELLANEOUS REFERENCE DATA

Use of Propagation Charts

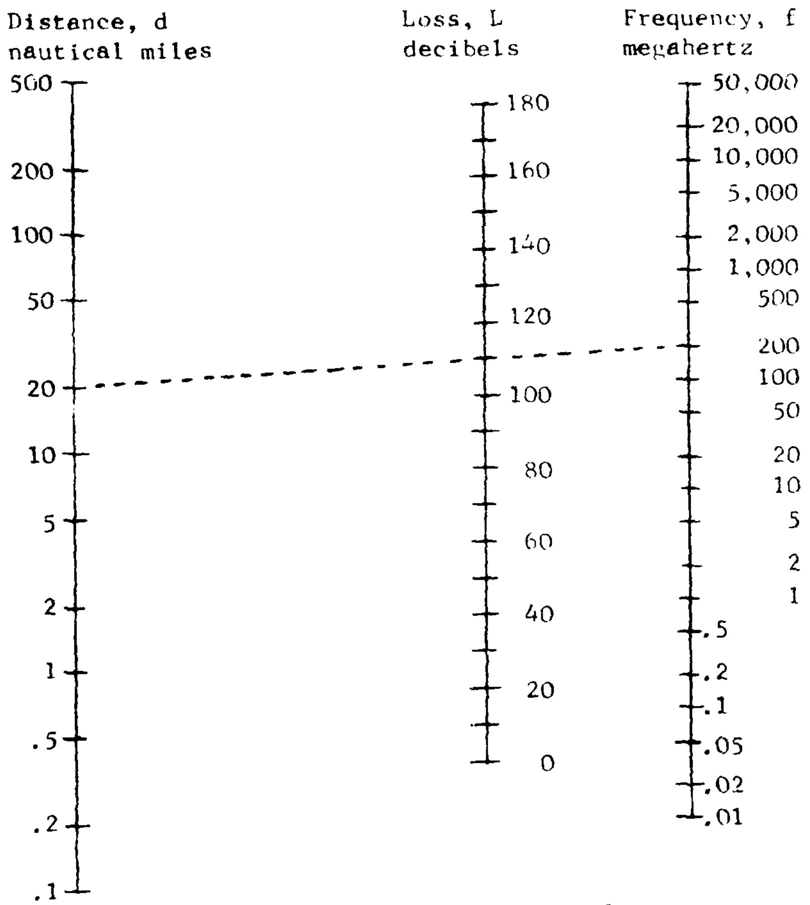
Five propagation charts are provided in this appendix, figures C-3 through C-7. There are four general levels at which propagation loss can be analyzed. The first is a simple free space loss computation, figure C-1. This can be quite accurate for unobstructed paths and can be assumed to vary with time/position with an approximate Rayleigh distribution, figure C-2.

The second level is the use of a chart for determining loss beyond line of sight based upon measurements made over typical terrain, figures C-3 through C-7. Terrain rather than antenna height will be the dominant source of error, so that the 25 ft. height used in the figures would apply to antennas from ground level to about 100 ft. These charts will provide a very rough estimate of the field strength that could be expected from various sites within several hundred miles of a spectrum measurements van. The variations with time/position can be expected to be Rayleigh distributed (maximum signal strength will be 12 dB above the median). The break point on the charts(the point at which loss sharply increases) will vary with terrain/antenna height/atmospheric conditons and can be expected to deviate from the path distance shown on the charts by as much as 2:1 during anomolous propagation conditions.

The third level of analysis makes use of a computer model to include the elevations at the end points of the path and several high points in the terrain along the path. Factors such as exact antenna heights, terrain roughness, terrain conductivity, frequency, sea level permittivity, humidity, precipitation, bandwidth, level of statistical availability with time/position, and polarization may be included. When two points are sufficiently far apart so that propagation loss will be substantially greater than that for free space, accuracy will suffer (see section 3.6, Site Coverage).

The fourth level of analysis is to go into the field and make an actual field strength measurement. Such measurements show considerable variation from day to day, month to month, and with the location at which the measurement is made. When long term measurements are made (over a number of days) the variation in signal strength tends to be close to Rayleigh distributed when the median path loss is considerably greater than that of free space (a long path). When the path loss is not significantly greater than that of free space, yet long enough to exhibit considerable fading, the fading statistics are apt to be about half those represented by the Rayleigh distribution (divide the numbers on the signal strength scale of figure C-2 by two). The Rayleigh distribution represents an upper limit for fading statistics in the case of actual measured path loss.

Figure C-1 , Path Attenuation Between Isotropic Antennas



1 nautical mile = 1.852 kilometer = 6076 feet

Equation: f is in megahertz, L in decibels

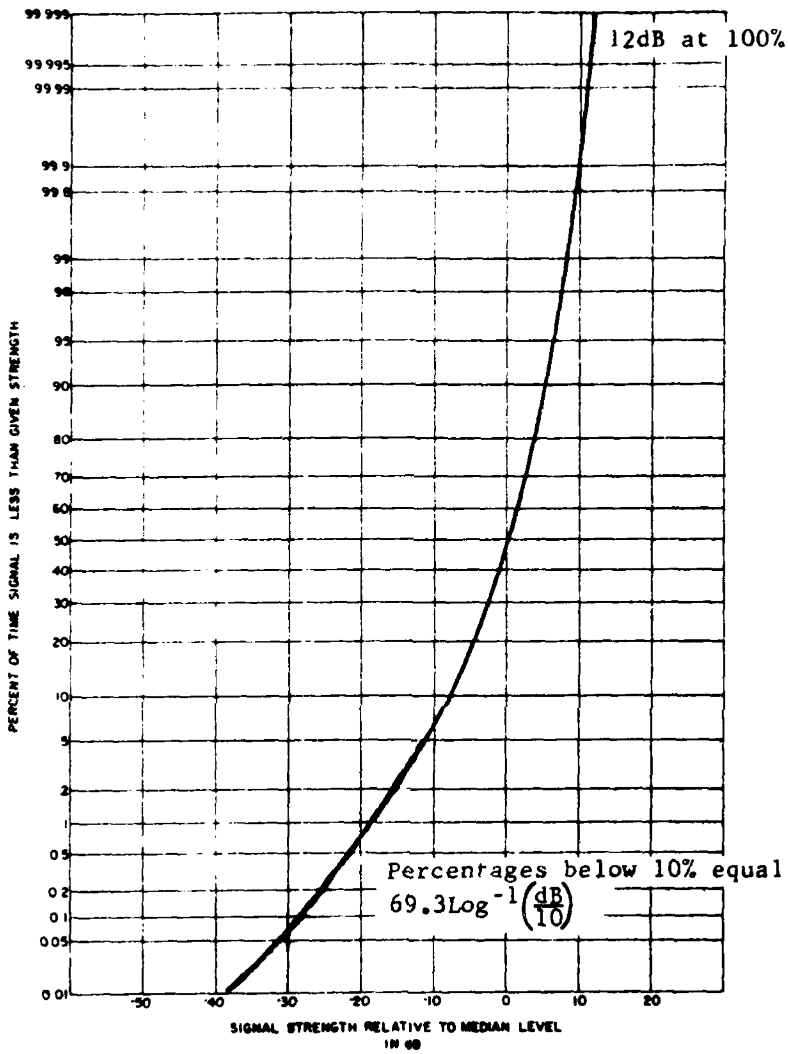
$L = 37.8 + 20 \log f + 20 \log d$ for d in nautical miles

$L = 36.6 + 20 \log f + 20 \log d$ for d in statute miles

$L = 32.5 + 20 \log f + 20 \log d$ for d in kilometers

Example shown: Read across dotted line, Distance = 20 nautical miles, frequency = 200 megahertz, free space loss = 110 decibels

Figure C-2, RAYLEIGH DISTRIBUTION OF FADING STATISTICS



The RMS level is 1.6 dB above the median level.
The average level is .5 dB above the median level.

The Rayleigh distribution applies to such phenomena as variation in propagation about the median path loss (see median propagation path loss charts), the distribution of the amplitude of thermal noise in a receiver, and the fluctuation in the strength of a radar return from scan to scan.

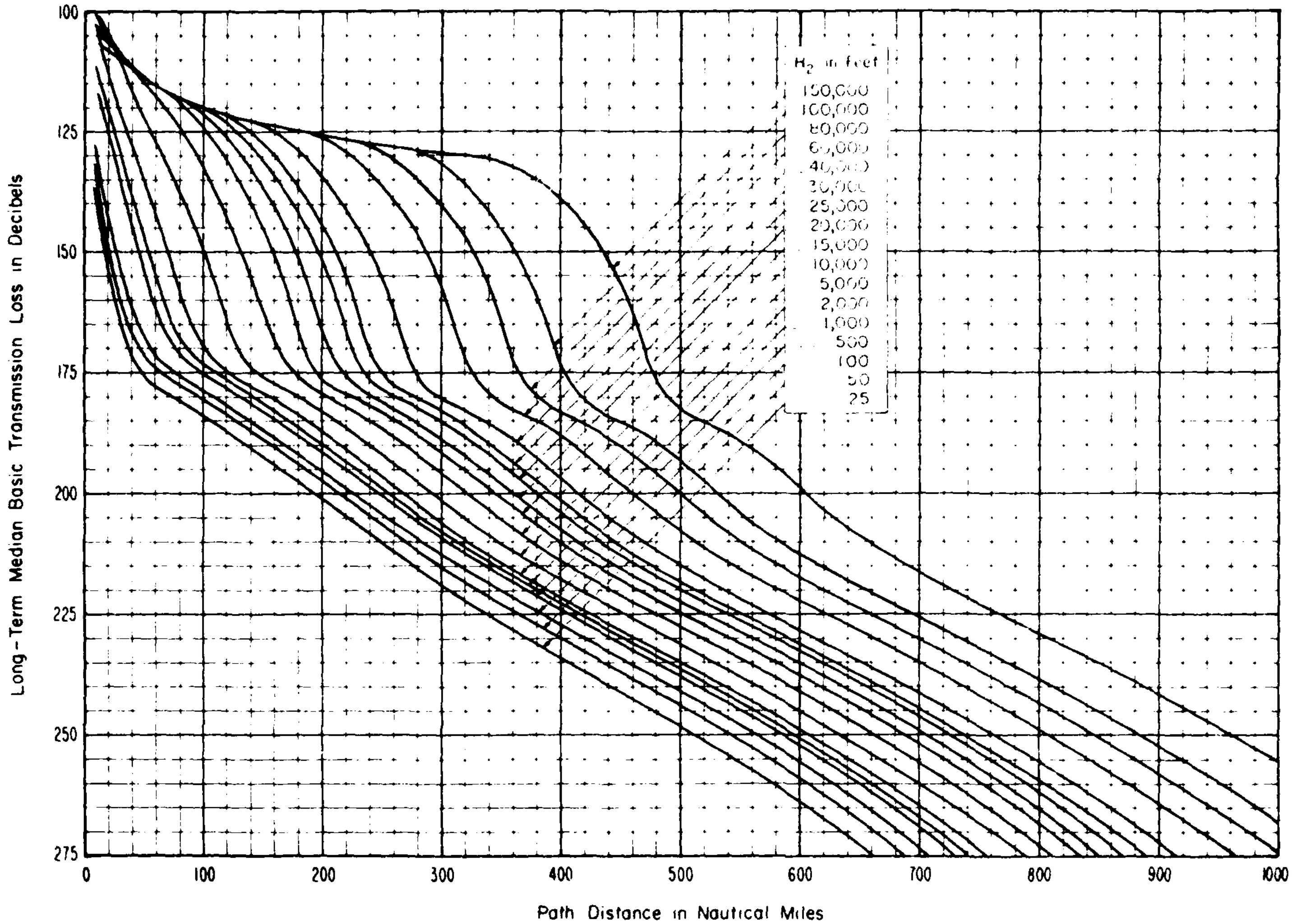


Figure C-3, Basic transmission loss versus distance; F = 125 MHz, H_1 = 25 ft.

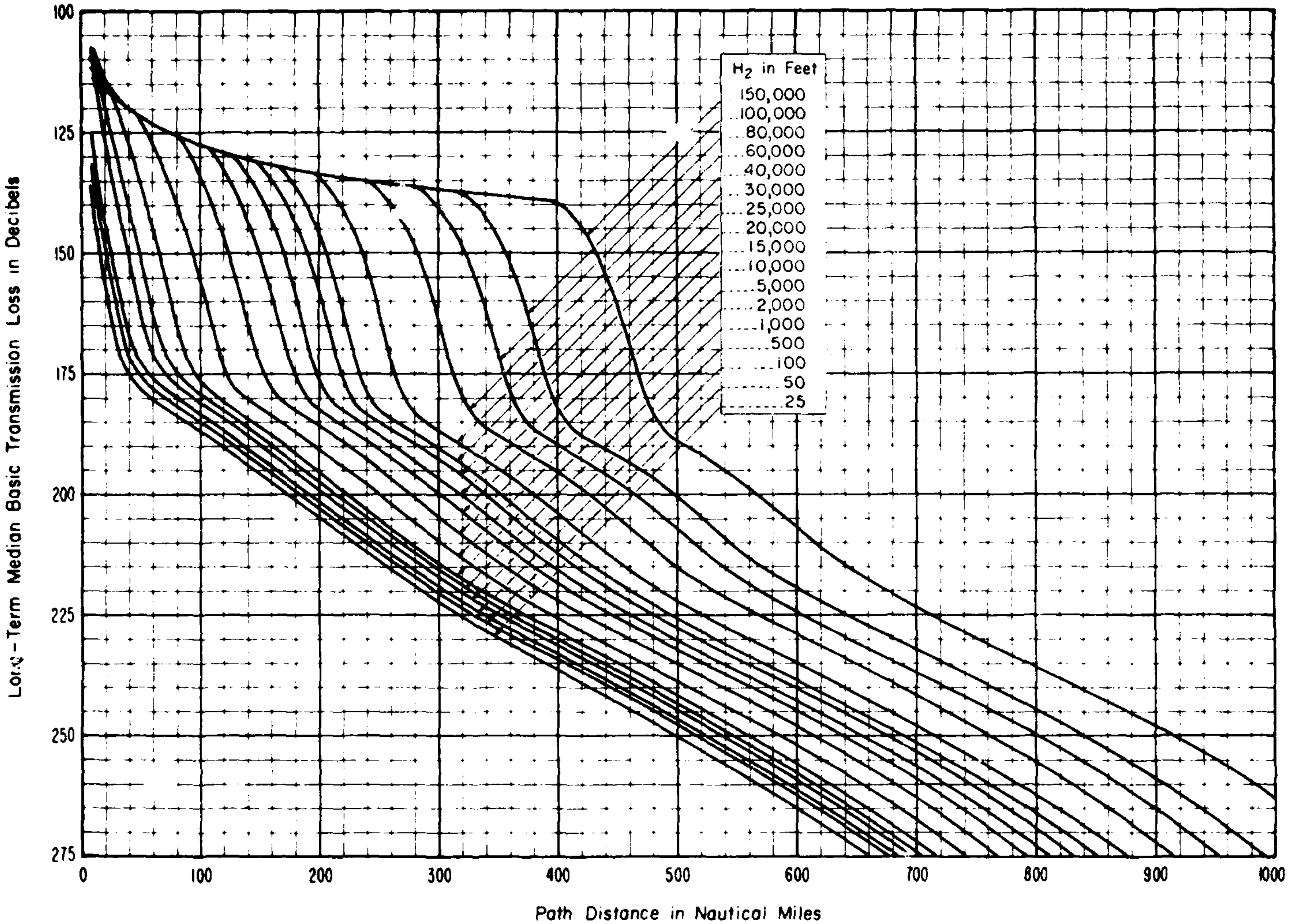


Figure C-4. Basic transmission loss versus distance; F = 300 MHz, H_1 = 25 ft.

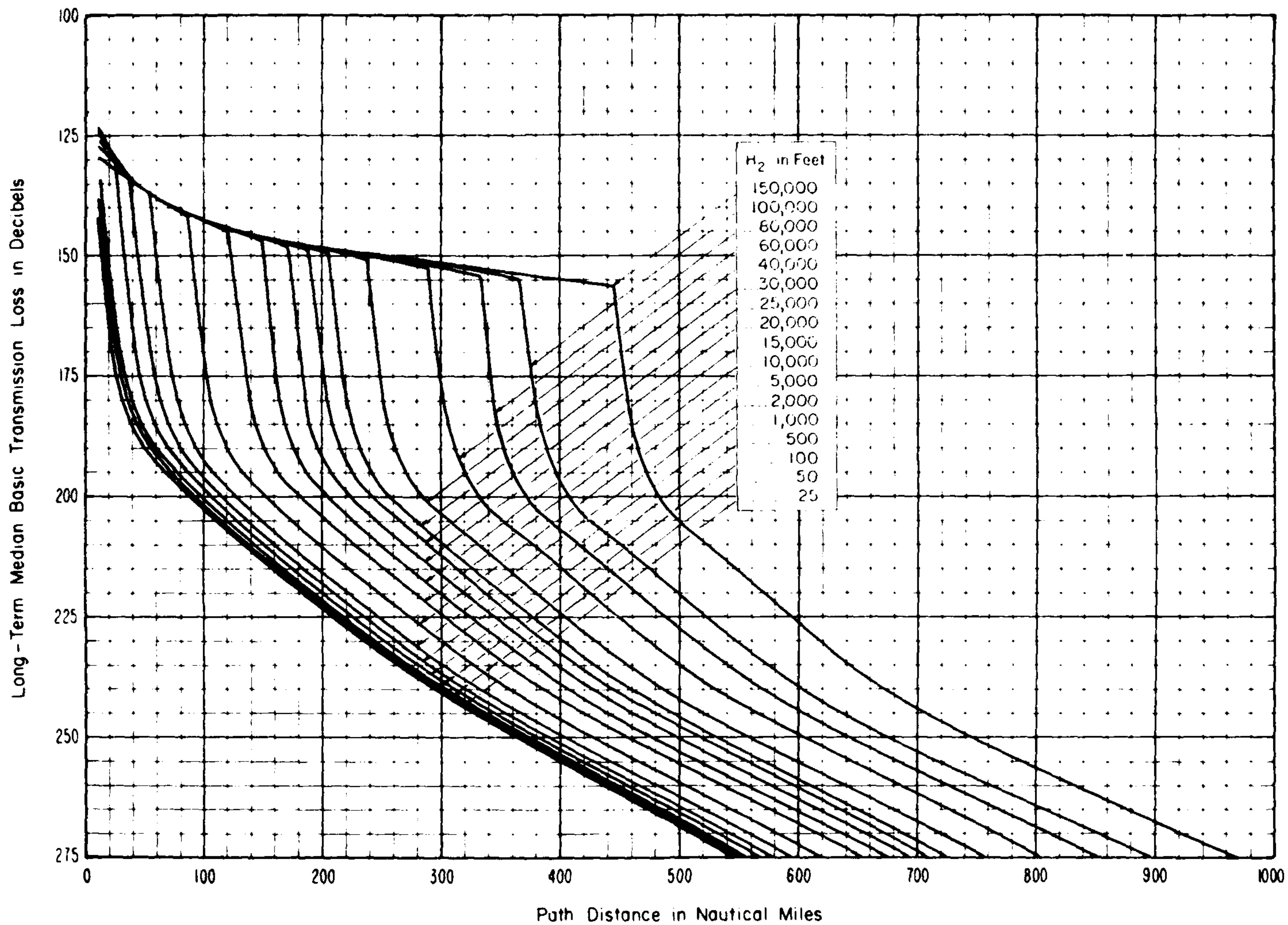


Figure C-5, Basic transmission loss versus distance; F = 1.6 GHz, H_1 = 25 ft.

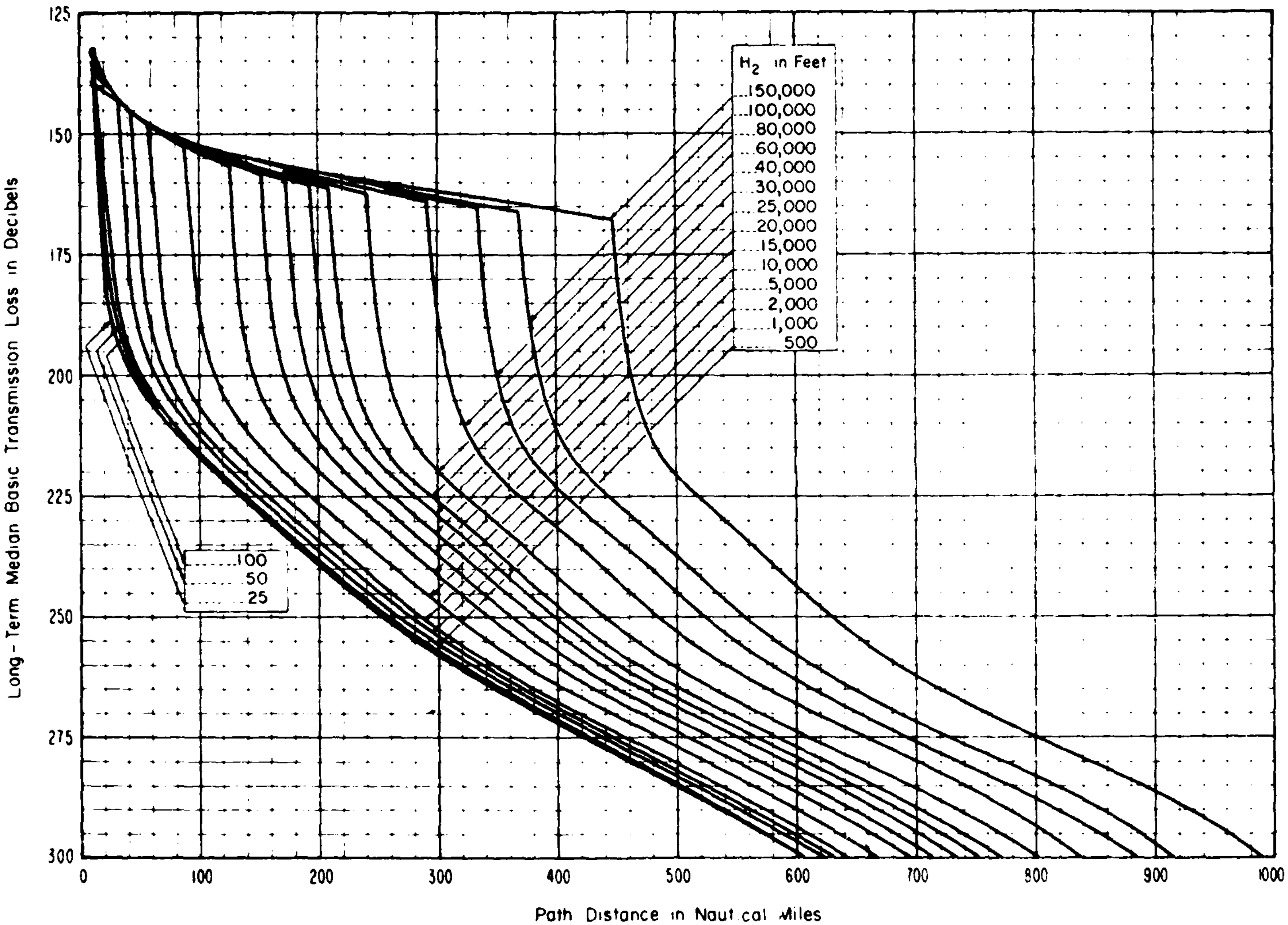


Figure C-6, Basic transmission loss versus distance; F = 5.1 GHz, H_1 = 25 ft.

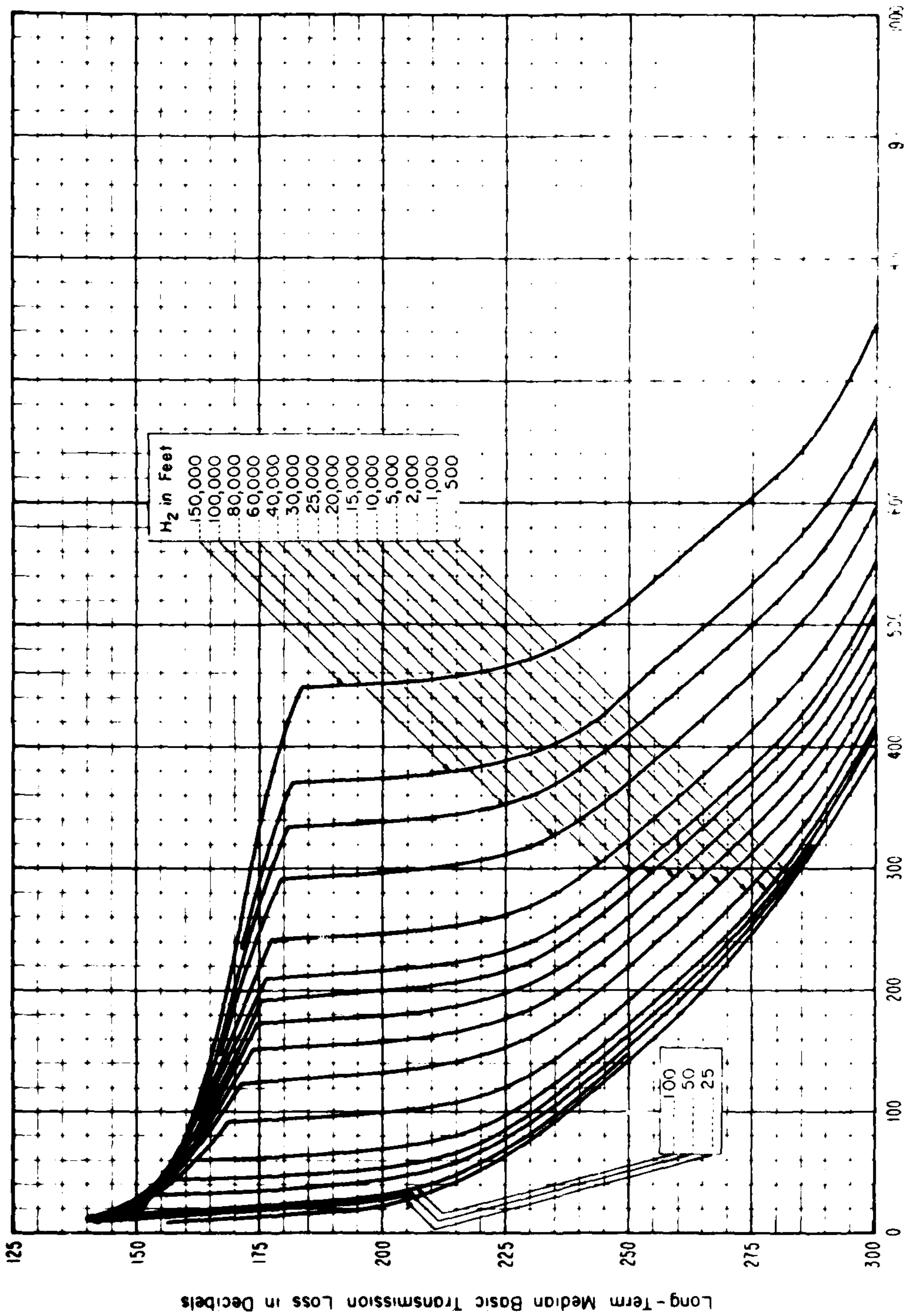
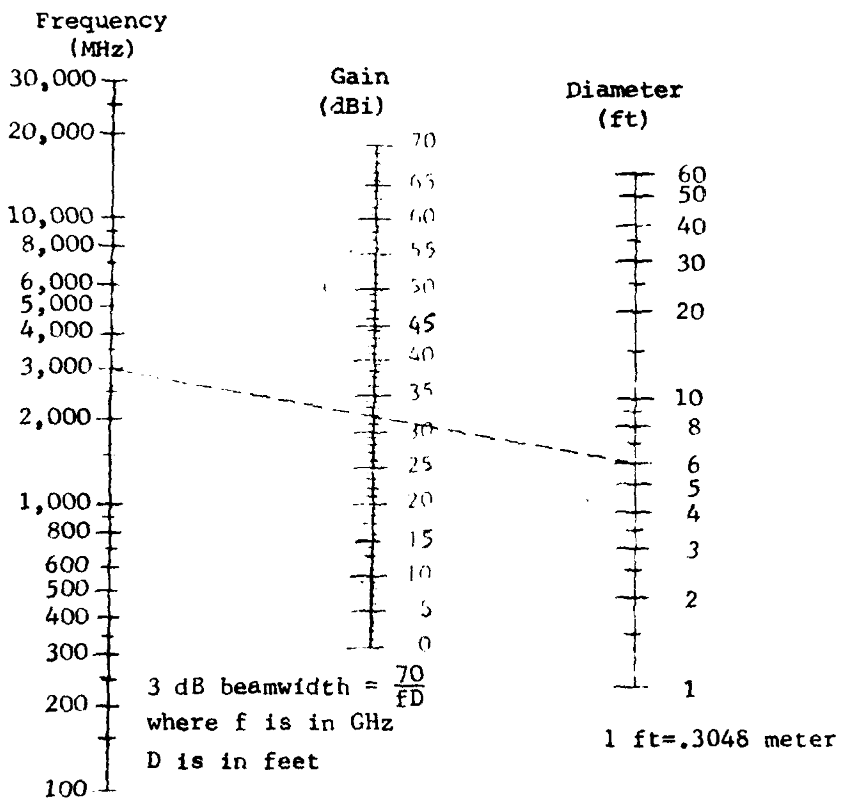


Figure C-7, Basic transmission loss versus distance, F = 15.5 GHz, H_1 = 25 ft.

Figure C-8. NOMOGRAM FOR DETERMINATION OF POWER GAIN OF PARABOLIC REFLECTOR



Equation: G = 20 log D + 20 log f - 52.6

(nominal 55% antenna efficiency)

Example shown: Frequency = 3000 MHz; Diameter = 6 feet; Gain = 32 dBi

Noise Spectra Calculations

1. Random Noise

Random noise is also termed white noise and Gaussian noise. It consists of overlapping pulses of random duration and amplitude. When the noise is sampled over a fixed frequency range (i.e. band limited), then the amplitude is Rayleigh distributed (see figure C-2). Since the energy is evenly distributed across the frequencies being sampled, the detected noise power in a receiver (such as a spectrum analyzer) will be a linear function of the receiver's intermediate frequency (IF) bandwidth.

Example:

A spectrum analyzer (a peak amplitude reading instrument) is used to measure a source of random noise using a 1 KHz IF bandwidth, and the level is found to be -82 dBm or -112 dBW. It is desired to determine what the level would be if a 100 KHz IF bandwidth were used. The difference expressed in decibels is

$$10\text{Log}\ \frac{100\text{KHz}}{1\text{KHz}} = 20\ \text{dB}$$

The level would increase by 20 dB if the IF bandwidth were increased to 100 KHz; it would be -62 dBm or -92 dBW.

2. Pulsed Noise

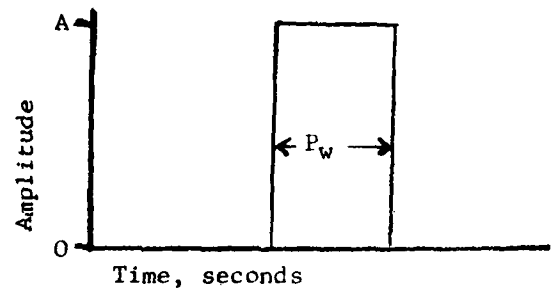
For the purposes of this section pulsed noise is defined as a single pulse or series of pulses that do not overlap. The characteristic sin x/x spectrum applies to phenomena such as lightning, ignition noise, TACAN, radar systems, and digital switching circuitry. Although the detected noise power (RMS signal level) in a receiver (such as a spectrum analyzer) is a linear function of the receiver's IF bandwidth when narrow bandwidths are used (bandwidth well below $2/P_w$, see figure C-9), distortion of the pulse shape makes it impossible to relate peak signal levels to RMS signal levels. Since spectrum analyzers are peak reading instruments, scale readings obtained with an IF bandwidth below $2/P_w$ are meaningless in absolute terms but do depict accurate levels relative to the maximum on the display (e.g. relative to the carrier of a radar system, or noise at the top of a band relative to that at the bottom of the band). The spectra of pulsed noise will have the characteristic sin x/x distribution shown in figure C-9.

Example:

It is desired to know the frequency off carrier that the first null will appear at, in a TACAN system with a 3.5 uSec. pulse width. From figure C-9 it can be seen that the first null is at $X = \pi$ corresponding to a frequency of 286 KHz. Since the actual TACAN pulse is not rectangular, the actual spectrum shows a sharp drop in amplitude at frequencies more than 200 kHz from the carrier. 12 uSec. pulse pairs (X mode) will produce spectrum peaks at multiples of 83 kHz from the carrier. 30 uSec. pulse pairs (Y mode) produce spectrum peaks 33 kHz apart. Texts concerning Fourier and Laplace transform analysis should be consulted for waveforms other than a simple rectangular pulse.

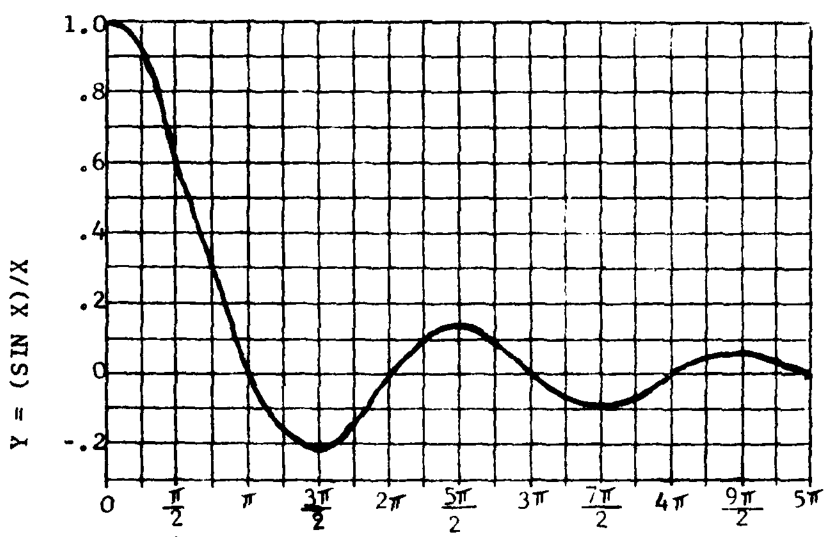
Figure C-9, PULSE SPECTRUM

Pulse



P_w is the pulse width in seconds

Spectrum



X in radians, to convert X axis to frequency multiply X value by $\frac{1}{\pi P_w}$

NOTES:
1. To convert Y axis values to dB use the following formula:

   $dB = 20 \mathrm{Log} |Y|$

2. Negative Y values represent a change in phase of 180° in the spectrum components.

3. When the pulse is used to modulate a carrier, the zero frequency (X = 0) represents the carrier frequency.

APPENDIX D

EQUIPMENT INVENTORY

1. Noise figure meter and noise source
2. Resistance standards (precision resistors)
3. Voltage standard (DC voltmeter and power supply)
4. HF receiver for WWV monitor
5. Broadcast television 5MHz-color subcarrier comparator, for 1 part in 10^9 to 10^{11} accuracy.
6. Frequency meter/counter
7. 10 KHz to 18 GHz signal generators (two)
8. Audio frequency signal generator
9. Audio distortion measurement set (10 mVolt sensitivity)
10. Portable VOM
11. Oscilloscope, full capabilities
12. RF power meter
13. Portable field intensity meter with directional antennas
14. Spectrum analyzer,with TWT/solid state preamps, cables, filters, directional antennas, etc. 10 kHZ to 18 GHz
15. Vehicle with DF capability, rapidly rotatable directional antennas
16. Mobile communications transceiver (162 to 174 MHz)
17. Communications transceiver (aircraft type) with antenna
18. Instrument Landing System receiver (aircraft type) with antenna
19. VOR receiver (aircraft type) with antenna
20. OMEGA/LORAN C receiver (mobile type)
21. LF ADF receiver (aircraft type) with antenna
22. ATCRBS transponder with antenna
23. CB type transceiver
24. "Skyphone"/radiotelephone transceiver, if needed
25. Miscellaneous: scope camera, compass, film, transit, tape measure, cables, plugs/jacks, extension cords,binoculars, sunglasses, log book, calculator with trig, electronic thermometers(for equipment temp.),etc.
26. Dual channel instrumentation recorder
27. Antenna coupling devices: cables, adapters, attenuators, directional couplers, flexible waveguide, tunable filters, detectors, mixers, etc.
28. Communications band scanning receivers (for activity measurements)
29. AC power generators
30. A/D converters, digital voltmeters, strip chart recorders(for monitoring primary/delayed AGC receiver bus)
31. Portable strip chart recorder, X-Y plotter
32. Audio spectrum analyzer
33. Time mark generator and reader, for use with recorders.
34. Multipath probe
35. Automated measurement system (for long term measurements)

Note: This is a hypothetical table and does not reflect equipment actually available through the various equipment loan pools and on site equipment.

APPENDIX E

ELECTROMAGNETIC RADIATION HAZARDS

1. General.

Agency policy, procedures and criteria are contained in Order 3910.3, Radiation Health Hazards and Protection. When field personnel are called upon to make measurements of potentially hazardous radio frequency radiation there are two precautions that should always be observed. The first is that the person making the measurements is no more resistant to RF hazards than anyone else, and such persons should take care not to expose themselves to excessive RF radiation levels. The second is that their activity should be limited to that of making measurements and no statements should be made in regard to the hazard or lack of hazard that the measured levels may represent. The American National Standard prepared by the ANSI C95 Subcommittee IV proposing standards for the 300 KHz to 100 GHz range is summarized in this appendix since it represents the present trend of such standards today.

2. Electromagnetic Field Safety Levels.

The following are maximum permissible exposure levels:

Frequency, f megahertz	Field Strength, volts per meter	Field Strength, milliwatts per square centimeter
.3 to 3	600	100
3 to 30	1800/f	$900/f^2$
30 to 300	60	1
300 to 1500	$3.4\sqrt{f}$	f/300
1500 to 100,000	130	5

3. Computation of Power Flux Density

Power flux density in mW/cm^2 is readily computed using the following formula:

$$\text{Power Flux Density} = K \frac{P}{D^2}$$

where P is the power in watts, D is the distance in feet or meters, K is .008 for D in meters, K is .086 for D in feet.

Example:

A 10,000,000 watt transmitter feeds an antenna exhibiting a 20 dB gain (an effective radiated power of 1,000,000,000 watts) at a position 240 feet away. The power flux density is then

$$.086 \frac{1,000,000,000}{(240)^2} = 1,493 \text{ mW/cm}^2$$

APPENDIX F VOR, DME/TACAN, ILS CHANNEL PLAN

Channel	VOR	DME/TACAN				ILS	
		Airborne		Ground			
	MHz	Int.Freq. MHz	Pulse Code μsec	Reply Freq. MHz	Pulse Code μsec	Localizer MHz	Glide Slope MHz
1X		1025	12	962	12		
1Y		1025	36	1088	30		
2X		1026	12	963	12		
2Y		1026	36	1089	30		
3X		1027	12	964	12		
3Y		1027	36	1090	30		
4X		1028	12	965	12		
4Y		1028	36	1091	30		
5X		1029	12	966	12		
5Y		1029	36	1092	30		
6X		1030	12	967	12		
6Y		1030	36	1093	30		
7X		1031	12	968	12		
7Y		1031	36	1094	30		
8X		1032	12	969	12		
8Y		1032	36	1095	30		
9X		1033	12	970	12		
9Y		1033	36	1096	30		
10X		1034	12	971	12		
10Y		1034	36	1097	30		
11X		1035	12	972	12		
11Y		1035	36	1098	30		
12X		1036	12	973	12		
12Y		1036	36	1099	30		
13X		1037	12	974	12		
13Y		1037	36	1100	30		
14X		1038	12	975	12		
14Y		1038	36	1101	30		
15X		1039	12	976	12		
15Y		1039	36	1102	30		
16X		1040	12	977	12		
16Y		1040	36	1103	30		
17X *	108.00	1041	12	978	12		
17Y *	108.05	1041	36	1104	30		
18X *		1042	12	979	12	108.10	334.70
18Y		1042	36	1105	30	108.15	334.55
19X	108.2	1043	12	980	12		
19Y	108.25	1043	36	1106	30		
20X		1044	12	981	12	108.3	334.10
20Y		1044	36	1107	30	108.35	333.95
21X	108.4	1045	12	982	12		
21Y	108.45	1045	36	1108	30		
22X		1046	12	983	12	108.5	329.90
22Y		1046	36	1109	30	108.55	329.75
23X	108.6	1047	12	984	12		
23Y	108.65	1047	36	1110	30		
24X		1048	12	985	12	108.7	330.50
24Y		1048	36	1111	30	108.75	330.35
25X	108.8	1049	12	986	12		
25Y	108.85	1049	36	1112	30		

* The frequencies associated with channels 17X, 17Y, and 18X are test frequencies. Assignments may be made to VOT's, ramp test equipment, radiating test generators, and other test facilities. (Area VOT assignments, however, are not recommended on channels 17X and 17Y). ILS, VOR, DME, and TACAN assignments should not be made on these channels. This has been coordinated with the Federal Communications Commission (FCC). See FCC Rules and Regulations Part 87.521(d).

Channel	VOR	DME/TACAN				ILS	
		Airborne		Ground			
	MHz	Int.Freq. MHz	Pulse Code μsec	Reply Freq. MHz	Pulse Code μsec	Localizer MHz	Glide Slope MHz
26X		1050	12	987	12	108.9	329.30
26Y		1050	36	1113	30	108.95	329.15
27X	109.00	1051	12	988	12		
27Y	109.05	1051	36	1114	30		
28X		1052	12	989	12	109.1	331.40
28Y		1052	36	1115	30	109.15	331.25
29X	109.2	1053	12	990	12		
29Y	109.25	1053	36	1116	30		
30X		1054	12	991	12	109.3	332.00
30Y		1054	36	1117	30	109.35	331.85
31X	109.4	1055	12	992	12		
31Y	109.45	1055	36	1118	30		
32X		1056	12	993	12	109.50	332.60
32Y		1056	36	1119	30	109.55	332.45
33X	109.6	1057	12	994	12		
33Y	109.65	1057	36	1120	30		
34X		1058	12	995	12	109.70	333.20
34Y		1058	36	1121	30	109.75	333.05
35X	109.8	1059	12	996	12		
35Y	109.85	1059	36	1122	30		
36X		1060	12	997	12	109.90	333.80
36Y		1060	36	1123	30	109.95	333.65
37X	110.00	1061	12	998	12		
37Y	110.05	1061	36	1124	30		
38X		1062	12	999	12	110.1	334.40
38Y		1062	36	1125	30	110.15	334.25
39X	110.20	1063	12	1000	12		
39Y	110.25	1063	36	1126	30		
40X		1064	12	1001	12	110.3	335.00
40Y		1064	36	1127	30	110.35	334.85
41X	110.40	1065	12	1002	12		
41Y	110.45	1065	36	1128	30		
42X		1066	12	1003	12	110.5	329.60
42Y		1066	36	1129	30	110.55	329.45
43X	110.60	1067	12	1004	12		
43Y	110.65	1067	36	1130	30		
44X		1068	12	1005	12	110.70	330.20
44Y		1068	36	1131	30	110.75	330.05
45X	110.80	1069	12	1006	12		
45Y	110.85	1069	36	1132	30		
46X		1070	12	1007	12	110.90	330.80
46Y		1070	36	1133	30	110.95	330.65
47X	111.00	1071	12	1008	12		
47Y	111.05	1071	36	1134	30		
48X		1072	12	1009	12	111.10	331.70
48Y		1072	36	1135	30	111.15	331.55
49X	111.20	1073	12	1010	12		
49Y	111.25	1073	36	1136	30		
50X		1074	12	1011	12	111.30	332.30
50Y		1074	36	1137	30	111.35	332.15
51X	111.40	1075	12	1012	12		
51Y	111.45	1075	36	1138	30		
52X		1076	12	1013	12	111.50	332.9
52Y		1076	36	1139	30	111.55	332.75
53X	111.60	1077	12	1014	12		
53Y	111.65	1077	36	1140	30		

Channel	VOR	DME/TACAN				ILS	
		Airborne		Ground			
	MHz	Int.Freq. MHz	Pulse Code μsec	Reply Freq. MHz	Pulse Code μsec	Localizer MHz	Glide Slope MHz
54X		1078	12	1015	12	111.70	333.5
54Y		1078	36	1141	30	111.75	333.35
55X	111.80	1079	12	1016	12		
55Y	111.85	1079	36	1142	30		
56X		1080	12	1017	12	111.90	331.1
56Y		1080	36	1143	30	111.95	330.95
57X	112.00	1081	12	1018	12		
57Y	112.05	1081	36	1144	30		
58X	112.10	1082	12	1019	12		
58Y	112.15	1082	36	1145	30		
59X	112.50	1083	12	1020	12		
59Y	112.25	1083	36	1146	30		
60X		1084	12	1021	12		
60Y		1084	36	1147	30		
61X		1085	12	1022	12		
61Y		1085	36	1148	30		
62X		1086	12	1023	12		
62Y		1086	36	1149	30		
63X		1087	12	1024	12		
63Y		1087	36	1150	30		
64X		1088	12	1151	12		
64Y		1088	36	1025	30		
65X		1089	12	1152	12		
65Y		1089	36	1026	30		
66X		1090	12	1153	12		
66Y		1090	36	1027	30		
67X		1091	12	1154	12		
67Y		1091	36	1028	30		
68X		1092	12	1155	12		
68Y		1092	36	1029	30		
69X		1093	12	1156	12		
69Y		1093	36	1030	30		
70X	112.30	1094	12	1157	12		
70Y	112.35	1094	36	1031	30		
71X	112.40	1095	12	1158	12		
71Y	112.45	1095	36	1032	30		
72X	112.50	1096	12	1159	12		
72Y	112.55	1096	36	1033	30		
73X	112.60	1097	12	1160	12		
73Y	112.65	1097	36	1034	30		
74X	112.70	1098	12	1161	12		
74Y	112.75	1098	36	1035	30		
75X	112.80	1099	12	1162	12		
75Y	112.85	1099	36	1036	30		
76X	112.90	1100	12	1163	12		
76Y	112.95	1100	36	1037	30		
77X	113.00	1101	12	1164	12		
77Y	113.05	1101	36	1038	30		
78X	113.10	1102	12	1165	12		
78Y	113.15	1102	36	1039	30		
79X	113.20	1103	12	1166	12		
79Y	113.25	1103	36	1040	30		
80X	113.30	1104	12	1167	12		
80Y	113.35	1104	36	1041	30		
81X	113.40	1105	12	1168	12		
81Y	113.45	1105	36	1042	30		

Channel	VOR	DME/TACAN				ILS	
		Airborne		Ground			
	MHz	Int.Freq. MHz	Pulse Code μsec	Reply Freq. MHz	Pulse Code μsec	Localizer MHz	Glide Slope MHz
82X	113.50	1106	12	1169	12		
82Y	113.55	1106	36	1043	30		
83X	113.60	1107	12	1170	12		
83Y	113.65	1107	36	1044	30		
84X	113.70	1108	12	1171	12		
84Y	113.75	1108	36	1045	30		
85X	113.80	1109	12	1172	12		
85Y	113.85	1109	36	1046	30		
86X	113.90	1110	12	1173	12		
86Y	113.95	1110	36	1047	30		
87X	114.00	1111	12	1174	12		
87Y	114.05	1111	36	1048	30		
88X	114.10	1112	12	1175	12		
88Y	114.15	1112	36	1049	30		
89X	114.20	1113	12	1176	12		
89Y	114.25	1113	36	1050	30		
90X	114.30	1114	12	1177	12		
90Y	114.35	1114	36	1051	30		
91X	114.40	1115	12	1178	12		
91Y	114.45	1115	36	1052	30		
92X	114.50	1116	12	1179	12		
92Y	114.55	1116	36	1053	30		
93X	114.60	1117	12	1180	12		
93Y	114.65	1117	36	1054	30		
94X	114.70	1118	12	1181	12		
94Y	114.75	1118	36	1055	30		
95X	114.80	1119	12	1182	12		
95Y	114.85	1119	36	1056	30		
96X	114.90	1120	12	1183	12		
96Y	114.95	1120	36	1057	30		
97X	115.00	1121	12	1184	12		
97Y	115.05	1121	36	1058	30		
98X	115.10	1122	12	1185	12		
98Y	115.15	1122	36	1059	30		
99X	115.20	1123	12	1186	12		
99Y	115.25	1123	36	1060	30		
100X	115.30	1124	12	1187	12		
100Y	115.35	1124	36	1061	30		
101X	115.40	1125	12	1188	12		
101Y	115.45	1125	36	1062	30		
102X	115.50	1126	12	1189	12		
102Y	115.55	1126	36	1063	30		
103X	115.60	1127	12	1190	12		
103Y	115.65	1127	36	1064	30		
104X	115.70	1128	12	1191	12		
104Y	115.75	1128	36	1065	30		
105X	115.80	1129	12	1192	12		
105Y	115.85	1129	36	1066	30		
106X	115.90	1130	12	1193	12		
106Y	115.95	1130	36	1067	30		
107X	116.00	1131	12	1194	12		
107Y	116.05	1131	36	1068	30		
108X	116.10	1132	12	1195	12		
108Y	116.15	1132	36	1069	30		
109X	116.20	1133	12	1196	12		
109Y	116.25	1133	36	1070	30		

Channel	VOR	DME/TACAN				ILS	
		Airborne		Ground			
	MHz	Int.Freq. MHz	Pulse Code μsec	Reply Freq. MHz	Pulse Code μsec	Localizer MHz	Glide Slope MHz
11[illegible]	116.30	1134	12	1197	12		
110Y	116.35	1134	36	1071	30		
111X	116.40	1135	12	1198	12		
111Y	116.45	1135	36	1072	30		
112X	116.50	1136	12	1199	12		
112Y	116.55	1136	36	1073	30		
113X	116.60	1137	12	1200	12		
113Y	116.65	1137	36	1074	30		
114X	116.70	1138	12	1201	12		
114Y	116.75	1138	36	1075	30		
115X	116.80	1139	12	1202	12		
115Y	116.85	1139	36	1076	30		
116X	116.90	1140	12	1203	12		
116Y	116.95	1140	36	1077	30		
117X	117.00	1141	12	1204	12		
117Y	117.05	1141	36	1078	30		
118X	117.10	1142	12	1205	12		
118Y	117.15	1142	36	1079	30		
119X	117.20	1143	12	1206	12		
119Y	117.25	1143	36	1080	30		
120X	117.30	1144	12	1207	12		
120Y	117.35	1144	36	1081	30		
121X	117.40	1145	12	1208	12		
121Y	117.45	1145	36	1082	30		
122X	117.50	1146	12	1209	12		
122Y	117.55	1146	36	1083	30		
123X	117.60	1147	12	1210	12		
123Y	117.65	1147	36	1084	30		
124X	117.70	1148	12	1211	12		
124Y	117.75	1148	36	1085	30		
125X	117.80	1149	12	1212	12		
125Y	117.85	1149	36	1086	30		
126X	117.90	1150	12	1213	12		
126Y	117.95	1150	36	1087	30		

APPENDIX G MICROWAVE LANDING SYSTEM (MLS), FREQUENCY CHANNELS

Channel Number	Frequency (MHz)	Channel Number	Frequency (MHz)	Channel Number	Frequency (MHz)
500*	5031.0	535	5041.5	570	5052.0
501	5031.3	536	5041.8	571	5052.3
502	5031.6	537	5042.1	572	5052.6
503	5031.9	538	5042.4	573	5052.9
504	5032.2	539	5042.7	574	5053.2
505	5032.5	540	5043.0	575	5053.5
506	5032.8	541	5043.3	576	5053.8
507	5033.1	542	5043.6	577	5054.1
508	5033.4	543	5043.9	578	5054.4
509	5033.7	544	5044.2	579	5054.7
510	5034.0	545	5044.5	580	5055.0
511	5034.3	546	5044.8	581	5055.3
512	5034.6	547	5045.1	582	5055.6
513	5034.9	548	5045.4	583	5055.9
514	5035.2	549	5045.7	584	5056.2
515	5035.5	550	5046.0	585	5056.5
516	5035.8	551	5046.3	586	5056.8
517	5036.1	552	5046.6	587	5057.1
518	5036.4	553	5046.9	588	5057.4
519	5036.7	554	5047.2	589	5057.7
520	5037.0	555	5047.5	590	5058.0
521	5037.3	556	5047.8	591	5058.3
522	5037.6	557	5048.1	592	5058.6
523	5037.9	558	5048.4	593	5058.9
524	5038.2	559	5048.7	594	5059.2
525	5038.5	560	5049.0	595	5059.5
526	5038.8	561	5049.3	596	5059.8
527	5039.1	562	5049.6	597	5060.1
528	5039.4	563	5049.9	598	5060.4
529	5039.7	564	5050.2	599	5060.7
530	5040.0	565	5050.5	600	5061.0
531	5040.3	566	5050.8	601	5061.3
532	5040.6	567	5051.1	602	5061.6
533	5040.9	568	5051.4	603	5061.9
534	5041.2	569	5051.7	604	5062.2

* Reserved as an MLS test channel.

Channnel Number	Frequency (MHz)	Channel Number	Frequency (MHz)	Channel Number	Frequency (MHz)
605	5062.5	645	5074.5	685	5086.5
606	5062.8	646	5074.8	686	5086.8
607	5063.1	647	5075.1	687	5087.1
608	5063.4	648	5075.4	688	5087.4
609	5063.7	649	5075.7	689	5087.7
610	5064.0	650	5076.0	690	5088.0
611	5064.3	651	5076.3	691	5088.3
612	5064.6	652	5076.6	692	6088.6
613	5064.9	653	5076.9	693	5088.9
614	5065.2	654	5077.2	694	5089.2
615	5065.5	655	5077.5	695	5089.5
616	5065.8	656	5077.8	696	5089.8
617	5066.1	657	5078.1	697	5090.1
618	5066.4	658	5078.4	698	5090.4
619	5066.7	659	5078.7	699	5090.7
620	5067.0	660	5079.0		
621	5067.3	661	5079.3		
622	5067.6	662	5079.6		
623	5067.9	663	5079.9		
624	5068.2	664	5080.2		
625	5068.5	665	5080.5		
626	5068.8	666	5080.8		
627	5069.1	667	5081.1		
628	5069.4	668	5081.4		
629	5069.7	669	5081.7		
630	5070.0	670	5082.0		
631	5070.3	671	5082.3		
632	5070.6	672	5082.6		
633	5070.9	673	5082.9		
634	5071.2	674	5083.2		
635	5071.5	675	5083.5		
636	5071.8	676	5083.8		
637	5072.1	677	5084.1		
638	5072.4	678	5084.4		
639	5072.7	679	5084.7		
640	5073.0	680	5085.0		
641	5073.3	681	5085.3		
642	5073.6	682	5085.6		
643	5073.9	683	5085.9		
644	5074.2	684	5086.2		

APPENDIX H INTERIM STANDARD MICROWAVE LANDING SYSTEM (ISMLS), FREQUENCY CHANNELS AND PAIRING

ISMLS					ILS	
Channel Number	Sequence of Use	Localizer (MHz)	Glideslope (MHz)	Reference* Beacon (MHz)	Localizer (MHz)	Glideslope (MHz)
1	13	5002.5	5227.2	5005.2	110.3	335.0
2	12	5002.1	5226.0	5005.2	109.9	333.8
3	10	5001.7	5224.8	5005.2	109.5	332.6
4	3	5002.3	5226.6	5005.2	110.1	334.4
5	11	5001.9	5225.4	5005.2	109.7	333.2
6	9	5001.5	5224.2	5005.2	109.3	332.0
7	8	5001.3	5223.6	5005.2	109.1	331.4
8	16	5003.1	5223.0	5005.2	110.9	330.8
9	15	5002.9	5222.4	5005.2	110.7	330.2
10	14	5002.7	5221.8	5005.2	110.5	329.6
11	4	5000.3	5226.9	5005.2	108.1	334.7
12	5	5000.5	5226.3	5005.2	108.3	334.1
13	1	5000.7	5222.1	5005.2	108.5	329.9
14	6	5000.9	5222.7	5005.2	108.7	330.5
15	7	5001.1	5221.5	5005.2	108.9	329.3
16	17	5003.3	5223.9	5005.2	111.1	331.7
17	18	5003.5	5224.5	5005.2	111.3	332.3
18	2	5003.7	5225.1	5005.2	111.5	332.9
19	19	5003.9	5225.7	5005.2	111.7	333.5
20	20	5004.1	5223.3	5005.2	111.9	331.1

*In the early design stages, reference beacons were required. With improved receiver design, this is no longer the case but the beacon frequencies are still in use. A few older receivers still require it, but it is primarily a legal requirement (FAR Part 171).

ISMLS					ILS	
Channel Number	Sequence of Use	Localizer (MHz)	Glideslope (MHz)	Reference Beacon (MHz)	Localizer (MHz)	Glideslope (MHz)
21	21	5008.5	5233.2	5011.2	110.3	335.0
22	22	5008.1	5232.0	5011.2	109.9	333.8
23	23	5007.7	5230.8	5011.2	109.5	332.6
24	24	5008.3	5232.6	5011.2	110.1	334.4
25	25	5007.9	5231.4	5011.2	109.7	333.2
26	26	5007.5	5230.2	5011.2	109.3	332.0
27	27	5007.3	5229.6	5011.2	109.1	331.4
28	28	5009.1	5229.0	5011.2	110.9	330.8
29	29	5008.9	5228.4	5011.2	110.7	330.2
30	30	5008.7	5227.8	5011.2	110.5	329.6
31	31	5006.3	5232.9	5011.2	108.1	334.7
32	32	5006.5	5232.3	5011.2	108.3	334.1
33	33	5006.7	5228.1	5011.2	108.5	329.9
34	34	5006.9	5228.7	5011.2	108.7	330.5
35	35	5007.1	5227.5	5011.2	108.9	329.3
36	36	5009.3	5229.9	5011.2	111.1	331.7
37	37	5009.5	5230.5	5011.2	111.3	332.3
38	38	5009.7	5231.1	5011.2	111.5	332.9
39	39	5009.9	5231.7	5011.2	111.7	333.5
40	40	5010.1	5229.3	5011.2	111.9	331.1

ISMLS					ILS	
Channel Number	Sequence of Use	Localizer (MHz)	Glideslope (MHz)	Reference Beacon (MHz)	Localizer (MHz)	Glideslope (MHz)
41	41	5014.5	5239.2	5017.2	110.3	335.0
42	42	5014.1	5238.0	5017.2	109.9	333.8
43	43	5013.7	5236.8	5017.2	109.5	332.6
44	44	5014.3	5238.6	5017.2	110.1	334.4
45	45	5013.9	5237.4	5017.2	109.7	333.2
46	46	5013.5	5236.2	5017.2	109.3	332.0
47	47	5013.3	5235.6	5017.2	109.1	331.4
48	48	5015.1	5235.0	5017.2	110.9	330.8
49	49	5014.9	5234.4	5017.2	110.7	330.2
50	50	5014.7	5233.8	5017.2	110.5	329.6
51	51	5012.3	5238.9	5017.2	108.1	334.7
52	52	5012.5	5238.3	5017.2	108.3	334.1
53	53	5012.7	5234.1	5017.2	108.5	329.9
54	54	5012.9	5234.7	5017.2	108.7	330.5
55	55	5013.1	5233.5	5017.2	108.9	329.3
56	56	5015.3	5235.9	5017.2	111.1	331.7
57	57	5015.5	5236.5	5017.2	111.3	332.3
58	58	5015.7	5237.1	5017.2	111.5	332.9
59	59	5015.9	5237.7	5017.2	111.7	333.5
60	60	5016.1	5235.3	5017.2	111.9	331.1

ISMLS					ILS	
Channel Number	Sequence of Use	Localizer (MHz)	Glideslope (MHz)	Reference Beacon (MHz)	Localizer (MHz)	Glideslope (MHz)
61	61	5020.5	5245.2	5023.2	110.3	335.0
62	62	5020.1	5244.0	5023.2	109.9	333.8
63	63	5019.7	5242.8	5023.2	109.5	332.6
64	64	5020.3	5244.6	5023.2	110.1	334.4
65	65	5019.9	5243.4	5023.2	109.7	333.2
66	66	5019.5	5242.2	5023.2	109.3	332.0
67	67	5019.3	5241.6	5023.2	109.1	331.4
68	68	5021.1	5241.0	5023.2	110.9	330.8
69	69	5020.9	5240.4	5023.2	110.7	330.2
70	70	5020.7	5240.8	5023.2	110.5	329.6
71	71	5018.3	5239.9	5023.2	108.1	334.7
72	72	5018.5	5244.3	5023.2	108.3	334.1
73	73	5018.7	5240.1	5023.2	108.5	329.9
74	74	5018.9	5240.7	5023.2	108.7	330.5
75	75	5019.1	5239.5	5023.2	108.9	329.3
76	76	5021.3	5241.9	5023.2	111.1	331.7
77	77	5021.5	5242.5	5023.2	111.3	332.3
78	78	5021.7	5243.1	5023.2	111.5	332.9
79	79	5021.9	5243.7	5023.2	111.7	333.5
80	80	5022.1	5241.3	5023.2	111.9	331.1

ISMLS					ILS	
Channel Number	Sequence of Use	Localizer (MHz)	Glideslope (MHz)	Reference Beacon (MHz)	Localizer (MHz)	Glideslope (MHz)
81	81	5026.5	5251.2	5029.2	110.3	335.0
82	82	5026.1	5250.0	5029.2	109.9	333.8
83	83	5025.7	5248.8	5029.2	109.5	332.6
84	84	5026.3	5250.6	5029.2	110.1	334.4
85	85	5025.9	5249.4	5029.2	109.7	333.2
86	86	5025.5	5248.2	5029.2	109.3	332.0
87	87	5025.3	5247.6	5029.2	109.1	331.4
88	88	5027.1	5247.0	5029.2	110.9	330.8
89	89	5026.9	5246.4	5029.2	110.7	330.2
90	90	5026.7	5245.8	5029.2	110.5	329.6
91	91	5024.3	5250.9	5029.2	108.1	334.7
92	92	5024.5	5250.3	5029.2	108.3	334.1
93	93	5024.7	5246.1	5029.2	108.5	329.9
94	94	5024.9	5246.7	5029.2	108.7	330.5
95	95	5025.1	5245.5	5029.2	108.9	329.3
96	96	5027.3	5247.9	5029.2	111.1	331.7
97	97	5027.5	5248.5	5029.2	111.3	332.3
98	98	5027.7	5249.1	5029.2	111.5	332.9
99	99	5027.9	5249.7	5029.2	111.7	333.5
100	100	5028.1	5247.3	5029.2	111.9	331.1

APPENDIX I AIR-GROUND COMMUNICATIONS CHANNEL PLAN

1. PURPOSE. This appendix describes the VHF radio frequency air traffic control communication system.

2. BACKGROUND. Aviation growth has required a commensurate increase in communication channels. Because more spectrum is not available, channel splitting techniques, have been employed. To meet the demand for new air/ground communication channels, FAA began implementing 25 kHz channel spacing in high altitude en route sectors in 1977. For unrestricted IFR operation a 720 channel radio communication capability is necessary.

3. FREQUENCY ASSIGNMENT PLAN.

a. ARTCC En Route. Air Route Traffic Control Center (ARTCC) en route assignments shall be selected on any 25, 50 or 100 kHz channel in the 118-121.4, 123,575-128.825 and 132.025-136 MHz bands. The emergency frequency 121.5 MHz shall have 100 kHz protection. ARTCC low altitude en route assignments shall receive 50 kHz protection wherever possible. At this writing, no air traffic control 25 kHz assignments have been planned except for the high altitude en route structure. Continued aviation growth will eventually dictate 25 kHz channels at lower altitudes and at terminals. As in the high en route program, sufficient advance notice will be provided. Where necessary to provide low altitude en route communications, 50 or 100 kHz assignments shall be removed from high altitude, en route service and 25 kHz assignments substituted until 25 kHz assignments are authorized for low altitude en route facilities.

b. ATC Terminal. Where possible, airport traffic control towers (ATCT's) shall be assigned one 100 kHz local control channel below 127 MHz. Additional ATCT requirements (approach control, departure control, local control, etc.) will be on 50 or 100 kHz assignments selected from the bands listed in 3a. Ground control assignments, normally will be on 50 or 100 kHz channels between 121.6 and 121.9. If adequate frequency protection cannot be obtained by using frequencies in this band, any frequency in the bands listed in 3a may be assigned. Clearance delivery may also be any 50 or 100 kHz channel in the bands listed in 3a. Where necessary to provide terminal communications, 50 or 100 khz assignments shall be removed from high altitude en route service and a 25 kHz assignment substituted. The need for 720 channel radio communication capability in terminal service areas is foreseen.

c. Flight Service Stations. Flight Service Stations (FSS) assignments will be selected on any 50 or 100 kHz channel in the 122.0-122.65 MHz band. At some future time, 25 kHz assignments may be necessary. Flight Service Stations will be assigned at least one channel on a 100 kHz increment. The frequencies 123.6 and 123.65 MHz are available to FSS for airport advisory. At part-time tower locations, the FSS may use the ATCT local control for airport advisory when the tower is closed.

4. ALLOCATION OF VHF FREQUENCIES. Figure 1 is a listing of the frequecies from 118.0 - 136.0 MHz and the service in which they are used. The band 136-137 MHz has been allocated to the Aeronautical Mobile (R) Service by the 1979 World Administrative Radio Conference. This band will be available for A/G communications in 1990. Planning of how best to use this band is already underway.

FIGURE 1
VHF ATC FREQUENCY ALLOCATIONS

FREQUENCY (MHz)	ATC SERVICE
118.0-121.4	Air Traffic Control
121.425-121.475	Band Protection for 121.5
121.5	Emergency Search and Rescue (ELT Operational Check, 5 Sec)
121.525-121.575	Band Protection for 121.5
121.6-121.925	Airport Utility and ELT Test
121.95	Aviation Instructional
121.975	Private Aircraft Advisory (FSS)
122.0	En Route Flight Advisory Service (EFAS)
122.025-122.075	FSS
122.1	FSS Usually Receive Only Associated with VOR (May Be Simplex)
122.125-122.175	FSS
122.2	FSS Common En Route Simplex
122.225-122.675	FSS
122.7	UNICOM - Uncontrolled Airports
122.725	UNICOM
122.75	UNICOM - Private Airports (Not Open to the Public) and Air-to-Air
122.775	UNICOM
122.8	UNICOM
122.825	UNICOM
122.85	Multicom - Special Use
122.875	UNICOM
122.9	Multicom - Special Use
122.925	Multicom - Natural Resources
122.950	UNICOM - Airports with a Control Tower

FREQUENCY (MHz)	ATC SERVICE
122.975	UNICOM - High Altitude Above 10,000 feet (3000 m)
123.0	UNICOM - Uncontrolled Airports
123.025	Helicopter Air-to-Air
123.05	UNICOM - Heliports
123.075	UNICOM - Heliports
123.1	Search and Rescue (Temporary Control Towers, Fly-ins may be assigned on a non interference basis to Search and Rescue).
123.125-123.275	Flight Test
123.3	Aviation Instructional - Gliders
123.325-123.475	Flight Test
123.5	Aviation Instructional - Gliders
123.525-123.575	Flight Test
123.6	FSS
123.625	Air Traffic Control
123.65	FSS
123.675-126.175	Air Traffic Control
126.2	Air Traffic Control - Military (Common)
126.225-128.8	Air Traffic Control
128.825-132.0	Operational Control (ARINC)
132.025-134.075	Air Traffic Control
134.1	Air Traffic Control - Military (Common)
134.125-135.825	Air Traffic Control
135.85	Flight Inspection
135.875-135.925	Air Traffic Control
135.95	Flight Inspection
135.975	Air Traffic Control

5. ALLOCATION OF UHF FREQUENCIES. Figure 2 is a table of the frequencies from 225-400 MHz normally available for ATC frequency assignments. Frequencies marked with an asterisk (*) are normally available only for specific ATC functions (see Figure 3).

FIGURE 2

UHF ATC FREQUENCY ALLOCATION
(frequency in MHz)

239.00	269.65	287.90	307.325	327.15	353.60	379.20
239.05	270.25	287.95	307.35	327.80	353.65	379.25
239.25	270.30	288.05	307.375	335.50	353.70	379.90
239.30	270.35	288.10	307.80	335.55	353.75	379.95
239.35	272.70	288.15	307.90	335.60	353.80	380.00
251.05	272.75	288.25	316.05	335.65	353.85	380.05*
251.10	273.45	288.30	316.10	338.20	353.90	380.10*
251.15	273.55	288.35	316.15	338.25	353.95	380.20
254.25	273.60	290.20	317.40	338.30	354.00	380.20
254.20	275.05	290.25	317.45	338.35	354.05	380.25
254.35	275.15	290.30	317.50	339.80	354.10	380.30
255.40	277.40	290.35	317.55	343.60	354.15	380.35
256.85*	278.30	290.40	317.60	343.65	357.60	381.40
256.875	278.85	290.45	317.65	343.70	360.60	381.45
256.90	278.45	290.50	317.70	343.75	360.65	381.50
257.60	278.50	290.55	317.75	343.80	360.70	381.55
257.65	278.55	291.60	319.00	343.85	360.75	381.60
257.70	279.50	291.65	319.10	343.90	360.80	381.65
257.75	279.55	291.70	319.15	343.95	360.85	385.40
257.80*	279.60	291.75	319.20	346.25	362.30	385.45
257.85	279.65	298.85	319.25	346.30	362.35	385.50
257.90	281.40	298.90	319.80	346.35	363.00	385.55
257.95	281.45	298.95	319.85	346.40	363.05	385.60
263.00	281.50	299.20	319.90	348.60*	363.10	385.65
263.05	281.55	306.20	319.95	348.65	363.15	387.00
263.10	282.20	306.25	322.30	348.70	363.20	387.85
263.15	282.25	306.30	322.35	348.75	363.25	387.10
269.00	282.30	306.90	322.40	350.20	370.85	387.15
269.05	282.35	306.95	322.45	350.25	370.90	397.85
269.10	284.60	307.00	322.50	350.30	370.95	397.90
269.15	284.65	307.05	322.55	350.35	371.85	397.95
269.20	284.70	307.10	323.00	351.70	371.90	398.85
269.25	284.70	307.125	323.05	351.80	371.95	398.90
269.30	285.40	307.15	323.10	351.85	372.00	398.95
269.35	285.45	307.175	323.15	351.90	377.05	
269.40	285.50	307.20	323.20	351.95	377.10	
269.45	285.55	307.225	323.25	352.00	377.15	
269.50	285.60	307.25	327.00	352.05	377.20	
269.55	285.65	307.275	327.05	353.50	379.10	
269.60	287.85	307.30	327.10	353.55	379.15	

Figure 3 lists the UHF frequencies available for specific ATC functions.

FIGURE 3
UHF Frequencies for Specific ATC Functions

Frequency (MHz)	ATC Function
255.40	Flight Service Station
257.80	Local Control
348.60	Ground Control
380.00	Flight Inspection
380.10	Flight Inspection
296.70	Tactical Special Use - High Altitude
321.30	Tactical Special Use - High Altitude
364.80	Tactical Special Use - High Altitude
369.90	Tactical Special Use - High Altitude

In some cases frequencies other than those listed in Figures 2 and 3 above will be assigned to ensure adequate service volume protection.

6. SERVICE VOLUME DIMENSIONS. There are no longer standard service volume sizes for communication facilities. However, Figure 4 is a listing of representative service volume dimensions. In practice, all service volumes are tailored to meet operational requirements.

FIGURE 4
Representative Service Volume Dimensions

Service	Service Volumes Altitudes in Feet (Meters) Maximum	Minimum	Service Volume Range in Nautical Miles (km)
Precision Approach Radar	5000 (1500) AGL	Ground Level	15 (28)
Helicopter	5000 (1500) AGL	Ground Level	30 (55)
Tower Control (local)	10000 (3000) AGL	Ground Level	30 (55)
Approach Control	25000 (7500) AGL	Ground Level	60 (111)
Departure Control	25000 (7500) AMSL	Ground Level	60 (111)
Low Altitude En Route	18000 (5500) AMSL	1000 (300) AGL	60 (111)
High Altitude En Route	45000 (13700) AMSL	18000 (5500) AMSL	150 (280)
Super High En Route	45000 (13700) AMSL	24000 (7300) AMSL	200 (370)
Ground Control	100 (30) AGL	Ground Level	2-10 (3.7-18.5)
Clearance Delivery	100 (30) AGL	Ground Level	2-10 (3.7-18.5)
ATIS	25000 (7500) AMSL	Ground Level	60 (111)
FSS	5000 (1500) AGL	Ground Level	40 (74)

APPENDIX J

Bulletin

FEDERAL COMMUNICATIONS COMMISSION
1919 M STREET, N.W.
WASHINGTON, D.C. 20554

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February 1982

VOLUMES OF FCC RULES AND REGULATIONS BY CATEGORIES

The FCC's rules and regulations are available from the Government Printing Office on a subscription basis. Subscription price is for an indefinite period and includes basic volume plus all amendments to be mailed to subscribers when issued. Parts are not sold separately, nor can they be supplied by the FCC. Domestic subscription includes U.S. Territories, Canada, and Mexico. Address requests to Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Part 0	Commission Organization	Volume I
Part 1	Practice and Procedure	(1980)
Part 13	Commercial Radio Operators	Price $18.00
Part 17	Construction, Marking and Lighting of Antenna Structures.	($22.50 Foreign)
Part 19	Employee Responsibilities and Conduct	
Part 2	Frequency Allocations and Radio Treaty Matters; General Rules and Regulations	Volume II (1976)
Part 5	Experimental Radio Services (Other Than Broadcast)	Price $23.00
Part 15	Radio Frequency Devices	($28.75 Foreign)
Part 18	Industrial, Scientific, and Medical Equipment	
Part 73	Radio Broadcast Services	Volume III
Part 74	Experimental, Auxiliary, and Special Broadcast and Other Program Distributional Services	(1980) Price $37.00 ($46.25 Foreign)
Part 81	Stations on Land in the Maritime Services	Volume IV
Part 83	Services on Shipboard in the Maritime Services	(1977) Price $26.00 ($32.50 Foreign)
Part 87	Aviation Services	Volume V
Part 90	Private Land Mobile Radio Services	(1979)
Part 94	Private Operational-Fixed Microwave Service	Price $17.00 ($21.25 Foreign)

(over)

Part	Title	Volume
See Note		Volume VI
Part 21	Domestic Public Fixed Radio Services (Other than Maritime Mobile)	Volume VII (1974)
Part 22	Public Mobile Radio Services	Price $15.00
Part 23	International Fixed Public Radiocommunication Services	($18.75 Foreign)
Part 25	Satellite Communications	
Part 31	Uniform System of Accounts for Class A and Class B Telephone Companies	Volume VIII (1978)
Part 33	Uniform System of Accounts for Class C Telephone Companies	Price $6.00 ($7.50 Foreign)
Part 34	Uniform System of Accounts for Radiotelegraph Carriers	Volume IX (1976)
Part 35	Uniform System of Accounts for Wire-Telegraph and Ocean-Cable Carriers	Price $15.00 ($18.75 Foreign)
Part 41	Telegraph and Telephone Franks	Volume X
Part 42	Preservation of Records of Communication Common Carriers	(1977) Price $28.00
Part 43	Reports of Communication Common Carriers and Certain Affiliates	($35.00 Foreign)
Part 51	Occupational Classification and Compensation of Employees of Telephone Companies	
Part 52	Classification of Wire-Telegraph Employees	
Part 61	Tariffs	
Part 62	Applications to Hold Interlocking Directorates	
Part 63	Extension of Lines and Discontinuance of Service by Carriers	
Part 64	Miscellaneous Rules Relating to Common Carriers	
Part 66	Applications Relating to Consolidation, Acquisition or Control of Telephone Companies	
Part 67	Jurisdictional Separations	
Part 68	Connection of Terminal Equipment to the Telephone Network	
Part 76	Cable Television Service	Volume XI (1976)
Part 78	Cable Television Relay Service	Price $17.00 ($21.25 Foreign)

NOTE: Volume VI has been discontinued and Parts contained therein are now available as separate pamphlets at the Government Printing Office (GPO) bookstore in Washington, D.C. and in the 18 GPO stores throughout the country. The pamphlets may also be obtained from the Superintendent of Documents. These pamphlets will be revised periodically, and current prices are as follows:

Part 95	Citizens Radio Service Subpart A - General Mobile (April 1977) Stock No. 004-000-00340-3; Price $1.50
	Subpart C - Radio Control (April 1977) Stock No. 004-000-00341-1; Price $.80; Minimum charge of $1.00 for each mail order.
	Subpart D - Citizens Band Radio (August 1978) Stock No. 004-000-00356-0; Price $ 1.50
	Subpart E - Technical Regulations (April 1977) Stock No. 004-000-00343-8; Price $.80; Minimum charge of $1.00 for each mail order.
Part 97	Amateur Radio Service (January 1979) Price $1.40
Part 99	Disaster Communications Service (April 1976) Price $.75

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